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Regional Geology of the Upper Blairmore Group and Bow Island Formation: A Subsurface Study in Southwestern Alberta

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Regional Geology of the Upper Blairmore Group and Bow Island Formation: a Subsurface Study in Southwestern Alberta

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Abstract

A comprehensive subsurface database was built from petrophysical logs of approximately 200 wells which penetrate the Lower Cretaceous successions from Townships 1 through 19, Ranges 19 west of 4th meridian to the edge of the deformed belt (Ranges 27 to 30 west of the 4th meridian). The subsurface database was used to construct a network of subsurface cross sections, including approximately 20 east-west and three north-south cross sections. Tops for the intertonguing marine and non-marine successions were identified from logs and outcrop work (in the deformed belt) for selected sites located proximal to areas with subsurface core-control. The outcrop and core sites were tied to subsurface logs by regional correlations. An intertonguing marine-nonmarine boundary was mapped throughout the study-area to distinguish those hydrocarbon pools that would have a more fluvial setting (Upper Blairmore Group) from those with more marine environments of deposition (upper Bow Island Formation). Log criteria for the distinction of marine and non-marine units included: the type of vertical changes in grain size (i.e. dominantly fining-upwards for nonmarine; coarsening-upwards for marine) and the degree of lateral continuity of correlatable units (low for nonmarine; high for marine).

The progradational regressive successions reflect the input of dominantly fluvial sediments into the basin during times of tectonic quiescence. The two fluvial formations belonging to the upper Blairmore Group include the Beaver Mines and Mill Creek formations. The fluvial parts of the Beaver Mines and Mill Creek formations are separated by a marine incursion, associated with a transgressive phase, of the Lynx Creek Member. The fluvial upper part of the Mill Creek Formation is known as the Bruin Creek Member.

A change from dominantly marine upper Bow Island sands and mudstones to continental or deltaic upper Blairmore (Mill Creek and Crowsnest formations) occurs across Ranges 26 and 27 W4 in the study area. This can be envisioned as an ancient shoreline with several embayments. Some wells drilled in this transition area will have marine Bow Island units, others will have continental successions.

In the region east of Range 25 W4, from Townships 1 through 19, Mannville-Bow Island terminology should be used. In areas west of Range 27 W4, near the limit of the deformed belt, Blairmore terminology should be used.

In the transition area from Range 26 to 27 W4, where both the Bow Island marine and the Mill Creek continental facies are found, both terminologies can be employed, depending upon which units are encountered. Care must be taken in this stratigraphic interpretation to be sure that the Lynx Creek marine units (part of the Blairmore Group) are not mistakenly identified as Bow Island marine successions.

1 Introduction

In the fall of 1997 the evaluation of new wells in the Claresholm area by the Alberta Energy and Utilities Board (EUB) resulted in a change in the name of the Claresholm Barons A pool to the Claresholm Blairmore B pool. There was some concern about this new name when the productive horizon was interpreted to be a Bow Island sand rather than an Upper Blairmore sand. It was recognized that differentiating between the Bow Island, Mannville and Blairmore units could be difficult as one moves from south central Alberta subsurface towards the southern Foothills of Alberta. The subsurface geology of Bow Island, Blairmore and Mannville stratigraphic units of southwestern Alberta is complicated and has not been well documented. This geological and stratigraphic complexity has made the application of Deeper Rights Reversion Zone Designations (DRRZD's) in southwestern Alberta, by the Department of Resource Development (DRD), difficult.

The purpose of this study was to define the area where the marine Bow Island Formation can be clearly distinguished from the continental Blairmore Group in southwestern Alberta. The Blairmore Group and its subsurface equivalents the Mannville and lower Colorado groups (Mellon, 1967, Pemberton and James, 1997; Leckie and Burden, in press) and associated stratigraphic units are described in this report. The present study was initiated in response to a request from the Minerals Operations Division, Alberta Department of Resource Development, to the AGS/EUB to define the eastern zero edge of the Blairmore Group in the southwestern Alberta subsurface (Figure 1), using core and log cross-section correlation.

2 Previous work

A summary of the stratigraphic nomenclature is given in Figure 2. The economic importance of Lower Cretaceous rocks of the southern Alberta Foothills has attracted geologists for over 100 years. George M. Dawson (1886) separated a lower coal-bearing series of sandstones and mudstones (the "Kootanie series") from an upper barren interval (the "Dakota series") covered with volcanogenic tuff and agglomerate (Fig. 2). Sir J. William Dawson (1886), on the basis of plant studies by his son George M. Dawson (1886), suggested to divide the strata into three series: a lower series of non-dicotyledonous flora ("Kootanie series"), an "Intermediate series" with some dicotyledonous remains and an upper series with dicotyledonous flora called the "Mill Creek series".

Detailed mapping by Leach (1914) and Rose (1917) led to the formal division of the Kootenay and Blairmore formations and the Crowsnest volcanics (Fig. 2). Berry (1929a and b) and McLearn (1929) examined plants and invertebrates in these rocks and placed the Kootenay in the Barremian, and the Blairmore in the Aptian-Albian. MacKay (1930) gave these conglomerates formation status in central Alberta and this formation now forms part of both the Luscar Group (Langenberg and McMechan, 1985) and the Blairmore Group.

Drillers working the Cretaceous of the subsurface of southern Alberta coined a plethora of names to describe sandstone bodies in the upper Blairmore strata. The Home Sandstone, Glauconitic Sandstone, McDougall-Segur Sand and Stockmans Sand were applied to identify different productive intervals in the upper Blairmore Formation (Hume, 1938 and 1939). These names

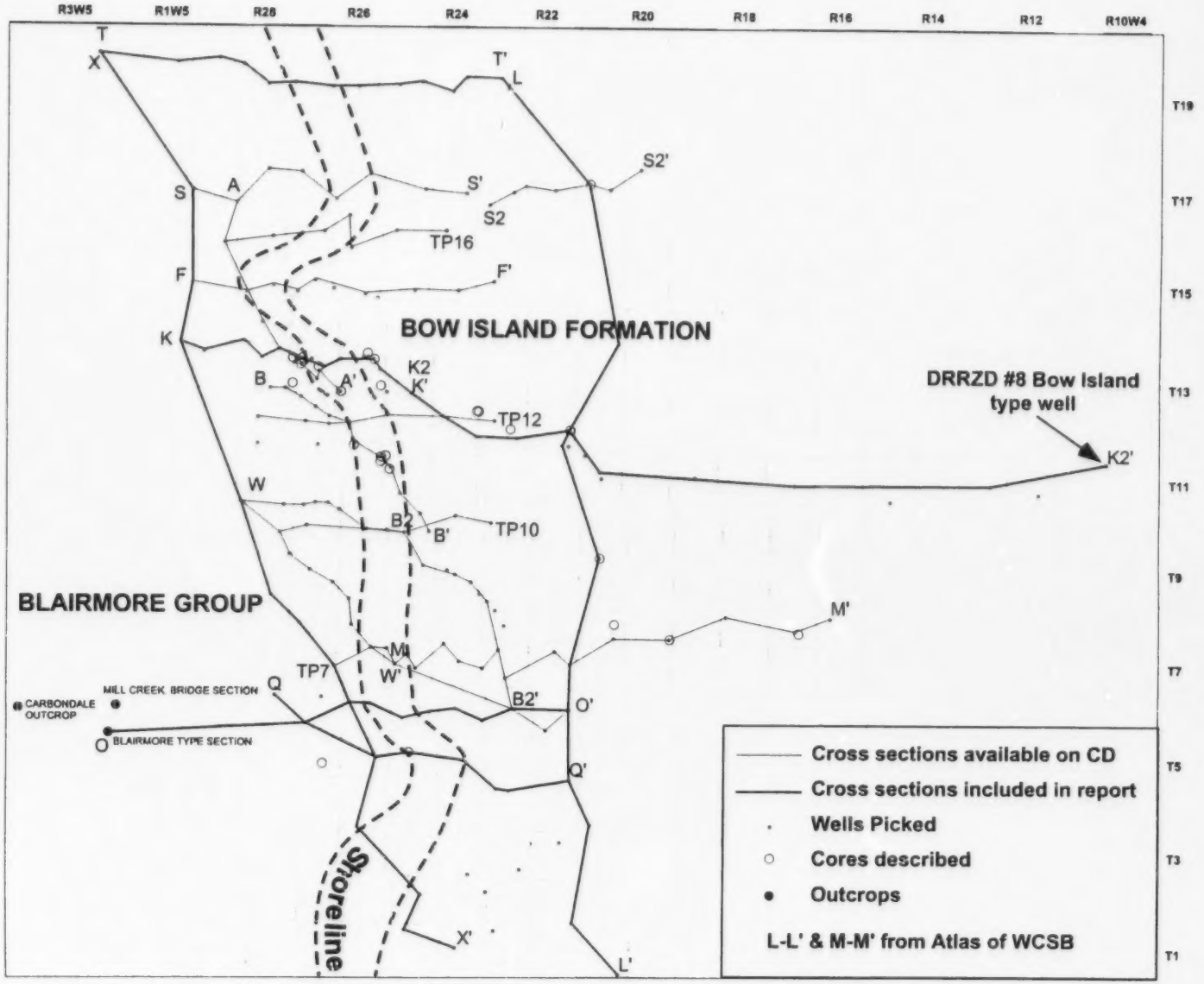

Figure 1. Map of the study area with cross section lines, well locations and the upper Bow Island shoreline as identified in this study. WCSB stands for Western Canada Sedimentary Basin.

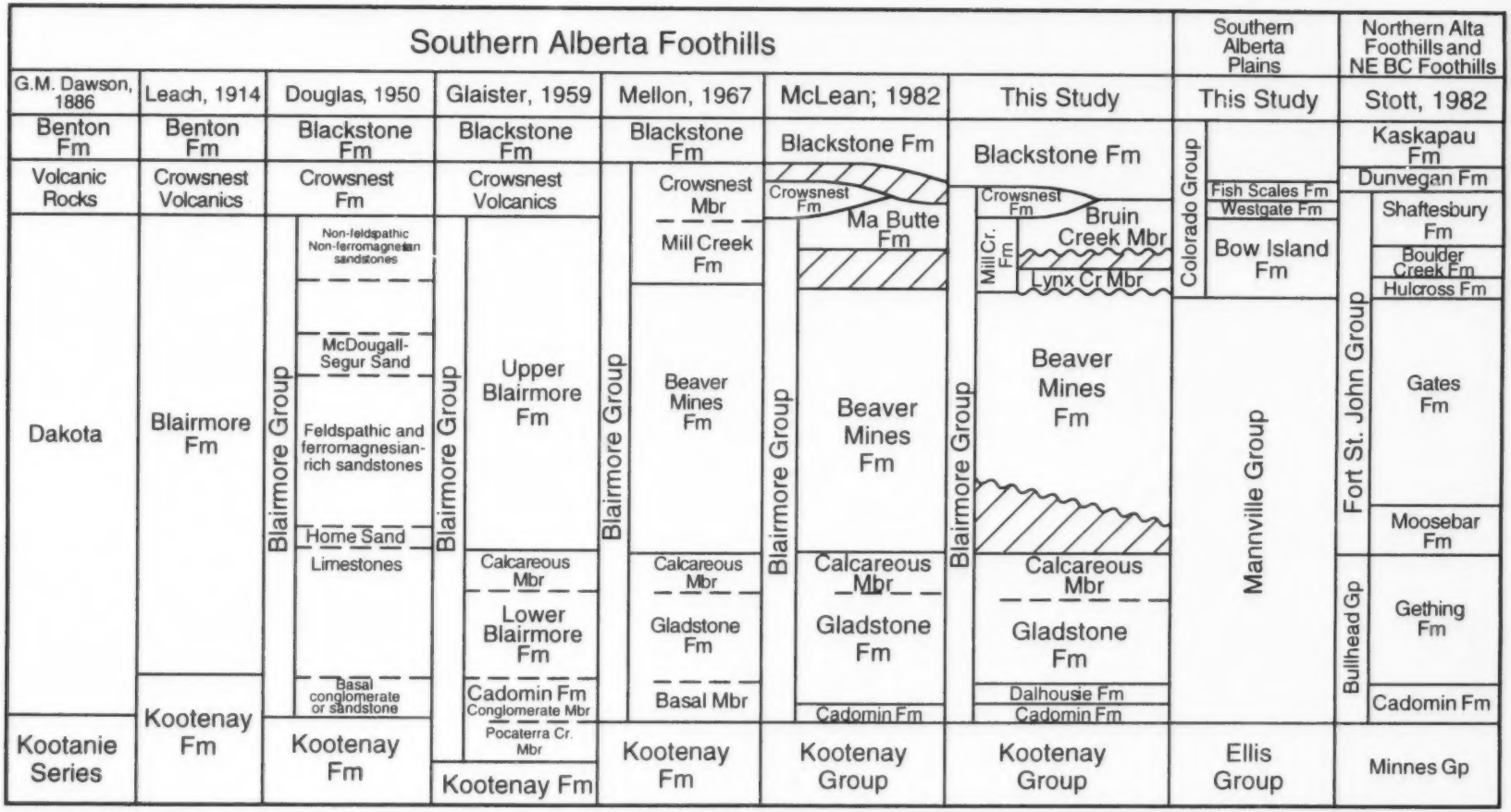

Figure 2. Stratigraphic correlation chart for the study and adjacent areas.

were not always used consistently.

The Bow Island Formation (Glaister, 1959; Leckie *et al.*, 1994) is stratigraphically equivalent to the upper part of the Blairmore Group and the Viking Formation of central Alberta.

Douglas (1950) and Glaister (1959) formally recognized a tripartite division of the Blairmore Group (Fig. 2). Cherty conglomerate and sandstone of the Cadomin Formation rest unconformably upon Kootenay Formation coal-bearing strata. The Dalhousie Formation is a chert and quartz sandstone overlying the conglomerate of the Cadomin Formation (Leckie and Cheel, 1997). The Dalhousie Formation is overlain by white to grey sandstone and mudstone, which become calcareous towards the top (lower Blairmore, Fig. 2). Upper Blairmore quartzose sandstone beds overlying the Calcareous Member were previously called the Home Sand or the Glauconitic Sand. An igneous pebble conglomerate was previously called the McDougall-Segur Conglomerate (Mellon, 1967; Norris, 1964). This conglomerate occurs at different stratigraphic positions. Consequently, the name has not been properly applied and can be abandoned (Leckie and Krystinik, 1995). Crowsnest volcanics or volcaniclastic siltstones and tuffaceous beds mark either a sharp or a gradational contact at the top of the Blairmore Group (Douglas, 1950).

Mellon and Wall (1963) recognised lithologic and paleontologic breaks in the Blairmore Group. They proposed a lower Blairmore (including the Calcareous Member), a middle Blairmore interval for feldspathic rocks lying above the Calcareous Member and below a prominent unconformity, and the upper Blairmore cherty and volcaniclastic rocks containing Bell's (1956) Mill Creek angiosperm flora. Mellon (1967) formalized this stratigraphy by introducing the Gladstone Formation for the lower Blairmore, the Beaver Mines Formation for the middle Blairmore, and the Mill Creek Formation for the upper Blairmore Group. Mill Creek strata included the Crowsnest Member as a volcaniclastic interval at the top of the Mill Creek Formation.

McLean (1982) established the Ma Butte Formation for "quartzose" strata comprising the lower part of Mellon's Mill Creek Formation, and considered the Mill Creek Formation to be redundant on the grounds that it was a sedimentological and biostratigraphic unit rather than a lithological unit (McLean, 1982; p. 4). The arguments used by McLean for abandonment of the properly-defined Mill Creek Formation (Mellon, 1967), so that the Crowsnest Member may be raised to formation status, are not convincing. For this reason, Leckie and Burden (in press) proposed that the term Mill Creek should be retained, especially since it has been used to describe these rocks since 1886 (G.M. Dawson, 1886). The volcanic rocks near the top of the Blairmore Group continue to be assigned to the Crowsnest Formation (Leckie and Burden, in press).

The mixed quartzose sandstones and mudstones in the basal part of the Mill Creek Formation, are recognized as a distinctive marine unit and are named the Lynx Creek Member (Leckie and Burden, in press).

3 Methodology

This regional study is based on cross sections that use about one well per township, although in the Claresholm area a closer spacing was used. Wells were chosen based on the availability of at least good gamma ray and resistivity logs, and the existence of core in the interval of interest (upper Blairmore and Bow Island units). There are two cross sections in the Atlas of the Western Canada Sedimentary Basin in the study area (Reinson *et al.*, 1994) and these were used as a starting point. Cross sections were initially constructed from paper copies of logs. A prominent bentonite marker in the Second White Specks was used as a stratigraphic datum.

Subsequently, the wells were digitized in the GeoGraphix system, which allows easy plotting of various logs in cross section. Some logs were already available in LAS format. Gamma Ray and resistivity logs were proven to be the most useful in the representation of the various stratigraphic units involved and are shown on the enclosed cross sections. The type sections of the Blairmore Group (Mellon, 1967; Hein *et al.*, 2000) along the Mill Creek were described and were used for outcrop to subsurface correlation (cross section OO' on Figure 1).

Sedimentary facies of cored intervals stored at the Core Research Centre (EUB) in Calgary were described, which aided in defining the shore line in the upper Blairmore/upper Bow Island interval and delineating the boundary between the Blairmore and Bow Island stratigraphic units.

4 Stratigraphy of the upper Blairmore Group

The upper Blairmore Group consists of the Beaver Mines, Mill Creek and Crowsnest formations (Figure 2).

4.1 Beaver Mines Formation

Mellon (1967) defined the Beaver Mines Formation as those strata that lie above the limestone beds (Calcareous Member) of the Gladstone Formation. Consequently, these beds are equivalent to the upper Mannville Formation. The detailed description of the Beaver Mines Formation in Mellon (1967) indicates that its thickness ranges from 253 m to 366 m. Lithologies consist of "interbedded green, fine-grained, crossbedded, feldspathic sandstone, dark green laminated siltstone and blocky, varicolored mudstone, the sandstones becoming thinner and finer-grained towards the top of the formation" (Mellon 1967; p. 20). The lower contact of the Beaver Mines Formation is sharp and overlies dark silty limestone beds of the Calcareous Member of the Gladstone Formation. The lower part of the Beaver Mines is often called the Home Sand and consists of medium to coarse-grained feldspathic sandstone with exotic volcanic pebbles and thin beds of dark green-grey siltstone (Mellon, 1967).

The upper Beaver Mines Formation consists of interbedded sandstone, siltstone and mudstone containing abundant in situ vertical roots, pedogenic slickensides and peds. Peds vary from a crumb stucture to 1 to 2 cm diameter blocky or columnar forms. Colors vary from olive green to red, and variegated greens and reds. Sandstone beds are decimetres to 6 m thick and fine to medium grained. Individual sandstones are sharp based; they may contain intraformational mudstone clasts and typically fine upwards. Due to the nature of the weathering, sedimentary

structures are generally difficult to discern. Calcite nodules in calcareous siltstone occur near the top of the Beaver Mines Formation at Mill Creek. The nodules are well rounded, 0.5 to 6 cm diameter, and some occur as vertical rhizoconcretions.

Age

Distinctive palynomorphs of the upper parts of the Beaver Mines Formation indicate an early to middle Albian age (Leckie and Burden, in press).

Interpretation

The sediments of the upper Beaver Mines Formation represent deposition in an alluvial plain setting with a shallow north or northeast dipping slope, and are characterized by sandy and muddy point-bar and overbank deposits. Oxidized fossils, in situ vertical roots, pedogenic slickensides and peds, indicating abundant soil horizons, suggest periods of time between episodes of sedimentation (McCarthy *et al.*, 1997). The coarser nature of the lower Beaver Mines Formation (Home Sand) indicates a slightly higher energy fluvial environment for this part of the succession.

4.2 Mill Creek Formation

The Mill Creek Formation consists of the Lynx Creek and Bruin Creek members.

Lynx Creek Member

The contact between the Lynx Creek Member and Beaver Mines Formation is sharp and conformable. It is represented by a change from greenish, chlorite-rich sandstones and variegated red/maroon and green siltstones and mudstone in the Beaver Mines Formation to white quartz-rich sandstone and dark grey/black mudstone and siltstone of the Lynx Creek Member. A regional low-angle unconformity separates the quartzose Lynx Creek Member from overlying more cherty Mill Creek strata, called the Bruin Creek Member. Locally, this unconformity is manifested by a prominent scour surface with thick bedded cherty sandstone above. In the subsurface, the lowermost Lynx Creek Member is recognized on petrophysical logs by prominent coarsening upward trends, identified with the marine transgression documented by Leckie and Burden (in press).

Interbedded mudstone, siltstone and quartzose sandstone of the Lynx Creek Member typically occur in coarsening-upward cycles approximately 10 m thick. Variegated strata are decidedly secondary in importance where they are infrequently identified at the top of the member. Flutes, prod marks, load structures, laminations, trough and hummocky cross beds, and wave ripples are common in the sandstones; mudstones are commonly bioturbated. The Lynx Creek Member is approximately 25 m thick at Mill Creek in the east, but thins and is erosionally truncated to the north and west where it is absent north of the Crowsnest Pass (Leckie and Burden, in press).

The Lynx Creek Member contains marine to brackish palynomorphs, microfossils, macrofossils and trace fossils. Sedimentary structures and fossils indicate that Lynx Creek Member strata

probably formed in shallow-marine and shoreline environments. The palynomorphs and microfossils suggest that correlative horizons in western Canada are the upper Hulcross Formation and upper Harmon and Cadotte members of the Peace River Formation of northeastern British Columbia and northwestern Alberta. The Lynx Creek Member may also be correlative with strata of the Joli Fou Formation of central Alberta.

Age

Lynx Creek Member strata are characterized by marine palynomorphs. Leckie and Burden (in press) have concluded that these rocks are of late middle Albian and perhaps earliest late Albian age.

Interpretation

The most recent interpretation is that the Lynx Creek might be Hulcross-equivalent in age (Figure 2). As such, this marine incursion is the first documentation of a major transgression into the Foothills of southern Alberta during middle Albian time. The sediments of the Lynx Creek Member represent the progradation of two and possibly three shoreline successions in a highstand systems tract conformably overlying the Beaver Mines Formation and formed in the late Middle Albian or earliest late Albian. The predominance of hummocky cross stratification and wave ripple lamination observed in outcrop indicates sedimentation primarily by wave processes. The outcrop on Carbondale River shows three cycles of sedimentation. The lower, poorly-defined upward-coarsening succession is overlain by a flooding surface. Cycles 2 and 3 coarsen upward from sandstone and siltstone of the offshore-transition through to lower shoreface zones. The low-angle, divergent lamination in the sandstone is interpreted as foreshore deposits which are capped by rooted siltstone and mudstone. The top of the third cycle passes into terrestrial deposits containing soils (Leckie and Burden, in press).

The upward-coarsening cycles at Mill Creek are interpreted to represent the more distal portions of those at Carbondale River, based on microfossils. Marine and brackish water dinoflagellates and acritarchs are relatively common and diverse at Mill Creek, while at Carbondale River they are neither common, nor diverse. This observation suggests a more restricted and probably a more brackish marine setting for the Carbondale River section (Leckie and Burden, in press).

Bruin Creek Member

The Bruin Creek Member of the Mill Creek Formation is named after Bruin Creek, near which the type section crops out. The type section of the Bruin Creek Member is located on the Livingston River, approximately 150 m south of the junction with Bruin Creek on the east side of the Forestry Trunk Road (Leckie and Burden, in press). The Bruin Creek Member occurs throughout the Rocky Mountain Foothills from the Carbondale River, north to the Livingston River. Reconnaissance observations indicate that the member may extend farther north, at least to the Bow River, and possibly beyond. Subsurface equivalents of the Bruin Creek Member in southwestern Alberta include the marine and nonmarine sediments of the Bow Island Formation (Figure 2).

The Bruin Creek Member varies from 87 m at Mill Creek to 133 m thick at Bruin Creek. The basal contact of the Bruin Creek Member is a sharp irregular surface which cuts underlying strata. The lowermost beds consist of medium to coarse-grained cherty sandstone and locally conglomerate, which rest erosively on Lynx Creek or Beaver Mines strata.

Internally, the Bruin Creek Member includes interbedded cherty sandstone with abundant rock fragments, varicolored mudstone, conglomerate and volcanic ash. It is in part laterally equivalent to the Crowsnest Formation and contains igneous-pebble conglomerates previously referred to as the McDougall-Segur conglomerate. The McDougall-Segur conglomerate is an informal term applied to strata consisting of laterally discontinuous beds of conglomerate up to 30 m thick and 3 km wide. Internally, McDougall-Segur beds are rich in igneous and volcanic clasts with lesser amounts of chert and quartzite set in a medium-grained, greenish-grey, arkosic matrix (Leckie and Krystinik, 1995).

On petrophysical logs the Upper Blairmore Group is characterized by blocky responses, with slightly fining-upwards successions on the resistivity logs, suggestive of interchannel braided river to meandering fluvial successions. It is difficult to pick correlatable units within the top of the Bruin Creek Member because of the increase in bentonite, and the apparently gradational contact with the overlying Crowsnest volcanics. However, in general, the Bruin Creek Member contains more mudstone and interbedded bentonites near the top, with paleosols; and the Crowsnest volcanics often are agglomerates, ash-fall tuffs, and volcanic flows.

Age

Arguments for the age of the Bruin Creek Member rely on the large assemblage of angiosperms, which suggest that the Bruin Creek Member is equivalent to the Bow Island Formation. These data imply an early late Albian age for the Bruin Creek Member.

Interpretation

The apparent lateral continuity of the lowermost sandstone of the Bruin Creek Member with an absence of siltstones and clays may suggest that the river, which deposited the sands, was not meandering, or may have been a low sinuosity system. Sediment above the basal sandstone exhibits a marked increase in rock fragment content, and the quartz and chert content decreases. Siltstone and clay represents floodplain and overbank deposits which were pedogenically altered. Sands were deposited by high-sinuosity meandering rivers. The water table was probably relatively low, or fluctuated as only minimal organic matter has been preserved. Bruin Creek Member rocks are generally devoid of sedimentary structures. Peds are common in mudstones; sandstones rarely exhibit fining upward successions with very rare crossbedding.

A terrestrial fluviatile and pedogenic setting similar to the Beaver Mines Formation, but of late Albian age, is inferred for these rocks. Detailed interpretations of the paleosols are in McCarthy *et al.*(1997; 1998).

4.3 Crowsnest Formation

Volcanics define the Crowsnest Formation and they represent one of the rare occurrences of extrusive volcanic deposits within Mesozoic strata of the Foothills and Rocky Mountains of western Canada east of the Rocky Mountain Trench. The Crowsnest Formation is a locally thick unit consisting of bedded alkaline volcanic deposits containing volcanic rock fragments and crystal clasts (often called agglomerates) at the top of the Blairmore Group (Hage, 1943; Price, 1962; Norris, 1964; Adair, 1986). Lava flows are rare and domes have not been identified. Nearly all of the volcanic rock fragments in these deposits are mildly potassic trachytes and phonolites (including blairmorite) with phenocrysts of sanidine, clinopyroxene, titanite, garnet (melanite), and analcite (Peterson, *et al.*, 1997). These rock fragments occur as blocks and bombs in the volcanic deposits. The largely volcanic rock fragments comprise up to 65% of the Crowsnest Formation. The remainder of the rock consists of individual crystal clasts and matrix. Xenoliths (wall rock material) are minor and include sedimentary, plutonic and metamorphic rocks (Adair and Burwash, 1996). Analcite phonolite (including blairmorite) is generally more common in the southern part of the outcrop area (Pearce, 1970). Black melanite garnet is common in the formation and can be used as an indicator of the lower contact with the Bruin Creek Member. Volcanic clasts are up to several metres across and on Ma Butte may weigh up to 15 tons (Pearce, 1970).

Trachytes and syenites of similar compositions were mapped along the Howell Creek in the Fernie (B.C.) area by Price (1965). The exact relationship of these trachytes to the Crowsnest volcanics is unknown. Stratigraphic and age dating of the Howell Creek intrusives indicate a lower Cretaceous age, similar to the Crowsnest volcanics (Gordy and Edwards, 1962).

The Crowsnest Formation is considered as a stratigraphic unit within the Blairmore Group following Mellon and Wall (1963) and Mellon (1967). The type section is that given by Price (1962) and measured in detail by Adair (1986) in the Coleman Thrust sheet along Highway 3 west of Coleman. The Crowsnest Formation has been informally divided in a lower and upper member (Adair and Burwash, 1996). The upper member is thicker bedded and contains more breccias than the lower member. Mellon (1967) defined a reference section for rocks exposed at Mill Creek. The volcanic rocks in the Mill Creek section are distal deposits of the Crowsnest volcanic event. They differ from the thick volcaniclastic strata at the type section near Coleman by containing more fine-grained bentonitic mudstones (ash-fall tuffs).

The lower contact of the Crowsnest Formation with the underlying clastics of the Bruin Creek Member is generally sharp (Norris, 1964; Pearce, 1970; Adair and Burwash, 1996). The upper contact with the Blackstone Formation is sharp with up to 40 m of relief (Norris, 1964). On Mill Creek, black marine mudstone of the Blackstone Formation lie directly on distal facies of the Crowsnest Formation, which are interbedded with the nonmarine Bruin Creek Member. At Willowby Ridge, in the Crowsnest Pass, the sediments of the Bruin Creek Member have a mineralogy representative of the Crowsnest Formation as far as 150 m below the first occurrence of unreworked Crowsnest volcanics (Adair, 1986; Adair and Burwash, 1996). Adair (1986) suggested that this and the presence of conglomerate clasts in the basal deposits indicate volcanic activity elsewhere, before deposition of Crowsnest Formation volcanic sediments near Coleman.

The Crowsnest Formation has a maximum thickness between 426 and 488 m (Price, 1962; Pearce, 1970; Norris, 1964) where exposed on the Coleman Thrust and on Ma Butte. The thickness of the formation, of individual bed thickness, and of clast size generally decreases away from this area (Pearce, 1970). The Crowsnest Formation has been mapped in the Foothills as far north as Hidden Creek at about 50° N latitude and as far south as Mill Creek (Price, 1962; Norris, 1964). However, in the more distal regions, the distribution of volcanics is patchy. For example, on Mill Creek more than 80 m of poorly-exposed volcaniclastic sediment is present, but elsewhere only isolated volcanic beds were observed. In the latter section, there is more evidence of siliciclastic nonmarine sedimentation with several tuffaceous, bentonitic and volcaniclastic beds with numerous paleosols. In the subsurface of the southern Alberta Plains, east of the outcrops in the Crowsnest Pass, bentonites can be recognized on the various logs of wells in equivalent stratigraphic intervals, interlayered with coarser clastics (see the cross sections attached to this report). These bentonites can be traced to bentonites in the Bow Island Formation, indicating that the distal facies of the Crowsnest Formation extends a long way to the east. In these distal areas, the volcanics could be easier dealt with as members of the Mill Creek and Bow Island formations.

The Crowsnest Pass area is reputed to have been the source of the legendary Lost Lemon Gold Mine. The source of the alleged gold deposits has been attributed to gravels in modern streams in this area (placer deposits) and more recently also from the volcanic rocks of the Crowsnest Formation (Stewart, 1990).

Petrography of distal Crowsnest volcanics

A reworked sand size crystal tuff from the Mill Creek Bridge section (Figure 1) was examined microscopically to investigate relationships of the distal volcanics with the volcanics at the type section of the Crowsnest Formation. Macroscopically, the rock is very fine-grained, massive and light grey in colour. In an aphanitic matrix, white quartz and feldspar crystals, up to 0.5 mm in size, abundantly occur.

Microscopically, the rock consists predominantly of fragments of pyroclastic quartz and alkali feldspar, which are cemented by aphanitic volcanic glass. The mineral crystals are usually broken. Volcanic glass and shards of chalcedony are less common. In accessory amount, muscovite, zircon and tourmaline, up to 0.2 mm in size, occur randomly. A few lithic particles of feldspar quartzite and sericitized clusters of unknown origin occur. The pyroclastic particles are randomly arranged and no flow structures are noticeable in the rock. Consequently, the rock appears to be rhyolitic and not trachytic nor phonolitic as could be expected from the volcanic rocks in the type section.

Under high magnification, volcanic glass shows weak optical anisotropy due to devitrification. Locally, irregular shaped pores occur abundantly in the matrix. Fine-grained vermicular chlorite, calcite, and less commonly chalcedony are precipitated in these void spaces. Glauconite grains, up to 0.1 mm in size, randomly occur within matrix voids as well.

Quartz grains make up about 70% of the total phenocrysts. Most commonly, quartz shows angular shards, up to 0.7 mm in size. They are sometimes corroded on the borders. Incomplete

euhedral quartz crystals occur as well. Almost entirely, quartz is strain-free, with unitary extinction. However, grains showing mosaic texture and undulatory extinction, rarely occur as well. Both solid and fluid inclusions unevenly occur in quartz. Some grains are abundant in fluid inclusions, which sometimes form bubble-wall textures typical for volcanics. Many grains are almost completely clear of fluid inclusions or include needles of rutile, which is typical for quartz of plutonic origin.

Alkali feldspars include albite and K-feldspar. In thin section, the precise proportion between sodic and potassium feldspar is hard to evaluate without staining it in sodium cobaltinitrite. However, by visual inspection, albite appears to be more common. Due to border resorption and cracking, the grains of feldspar are mostly incomplete. Euhedral and subhedral feldspar crystals occur randomly. They are up to 0.4 mm in size. Some of them are impregnated by calcite.

The matrix is almost always aphanitic. It is devitrified volcanic glass, which partly resembles chert. Very fine-grained illite, vermicular chlorite and dark-coloured impurities are also abundant in the matrix. The content of silica is probably very high, as the refractive index of the matrix is comparable to that of quartz.

The main mineral components (quartz, alkali feldspar and high-silica volcanic glass) indicate rhyolitic volcanism. The observed textures and mineral components do not suggest any mixing of rhyolitic material with other volcanic sources. No minerals typical for alkaline phonolites (typical for the Crowsnest volcanics at the type section) have been found in the sample. Consequently, the volcanism of the distal facies of the Crowsnest volcanics may be different from that at the type locality near Coleman.

Age

Radiometric dates of the Crowsnest Formation using K/Ar techniques range from 93.9 Ma to 101 Ma (Folinsbee *et al.*, 1957; Folinsbee *et al.*, 1961). A recent U/Pb date of 103± .5 Ma was obtained by dating of a single sanadine crystal from the volcanics exposed along Highway 3 at Coleman (J. Obradovitch, pers. comm., 1996) indicating a middle to late Albian age for the Crowsnest Formation. Bruin Creek Member palynomorphs from beds below volcanic ash show that the volcanism can be no older than late Albian (Leckie and Burden, in press).

Interpretation

The volcanoes which formed the Crowsnest Formation were on an inland flood plain centred near Coleman and were probably of high relief (Glaister, 1959; Norris,1964; Mellon, 1967; Pearce, 1970, Adair and Burwash, 1996). Source areas or pipes for the volcanic detritus are assumed to be located in the Ma Butte, Coleman, and George Creek areas where maximum sediment thicknesses occur (Pearce, 1970; Ricketts, 1982). Pearce (1970) interpreted the volcanic material to consist of agglomerates and tuffs (partially water reworked), volcanic sandstone, volcanic flows and dykes. Ricketts (1982) indicated that many of the beds had characteristics of hot laharic breccias (volcanic debris flows), containing primary sedimentary structures which may represent alluvial deposition by short-lived streams. In contrast, according to Adair and Burwash (1996), the deposits largely include pyroclastic volcanic breccia,

volcaniclastic debris flows, ash-fall deposits (tuff and lapilli tuff) and only minor mud flows. This conclusion is based on chilled margins, baked rock fragment margins, recrystallization and the presence of charred wood in coarse deposits, all indicating emplacement at elevated temperatures. Ash-fall is indicated by fine-grained deposits. Adair and Burwash (1996) indicate that the Crowsnest deposits are typical of explosive, subaerial volcanic eruptions. The explosive nature of the volcanism produced air-fall tuffs and destroyed previous lava flows. The structures typical for elevated temperatures are absent in some coarse grained deposits near the base of the formation and these deposits are interpreted to be laharic flow deposits (Adair and Burwash, 1996).

The most recent interpretation of these rocks is by Peterson *et al.* (1997), who conclude that most of the exposure on Ma Butte and along Highway 3 is compatible with fluvial erosion and redeposition of volcanic rocks. Concentrations of very large trachyte boulders (up to 10 m) can give an impression of flows, but these could never be traced laterally to define continuous horizons. This is supported by the presence of bed truncations, channel scours, caliche horizons, and synsedimentary faults. According to the descriptions, Peterson *et al.* (1997) make an exception for parts of the upper member, which they describe as a proximal volcanic deposit. This conclusion is based on the presence of thin shards of coal and flat, deformed volcanic fragments containing pyrite in a fine-grained schistose matrix. In addition, they describe a narrow gorge on Star Creek with altered, massive analcite phonolite. They interpret the Star Creek outcrop as a phonolite dome displaying abundant hydrothermal alteration and syn-extrusive brittle faults.

5 Stratigraphy of the Mannville and lower Colorado Groups

Late Aptian - early Albian successions of the Mannville Group accumulated along the margins and within the centre of the Western Interior Basin. A northward retreat of the late Early Albian epicontinental seaway near the end of Upper Mannville time, followed by a transgression of the boreal sea into south-central Alberta, resulted in an unconformity between the Upper Mannville sediments and the basal Colorado-Viking - Bow Island sands. However, in a few locations, the stratigraphy is continuous and mainly conformable until Late Albian/Early Cenomanian time (Williams and Stelck, 1975, Figure 3). The Beaver Mines through Mill Creek successions (Leckie and Burden, in press) preserve this more complete stratigraphy in the west.

By early Late Albian time, waters from the Gulf of Mexico merged with those originating in the Arctic, forming another epicontinental seaway (Figure 3). Northwest of the Sweetgrass Hills in the southern Canadian Rocky Mountain Foothills, marine Lynx Creek Member (Mill Creek Formation) sandstones unconformably overlie the Mannville-equivalent Beaver Mines Formation. The fluvial Bruin Creek Member sandstones disconformably overlie Lynx Creek sediments. In more distal basin-centre areas the marine Joli Fou mudstones and marine Bow Island-Viking sandstones were deposited unconformably upon the eroded Mannville successions (Leckie *et al.*, 1994).

The Bow Island Formation is overlain by the Westgate and Fish Scales formations (Bloch *et al.*, 1993). All these formations belong to the lower Colorado Group (Leckie *et al.*, 1994).

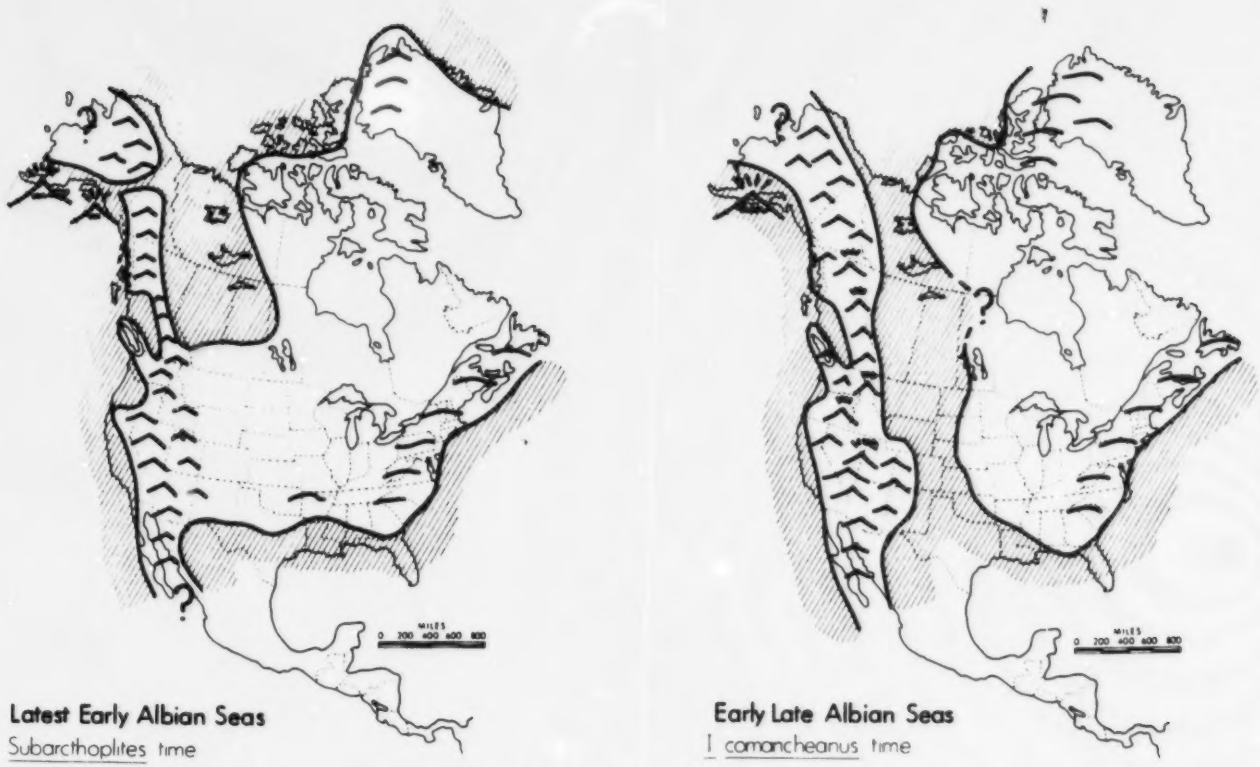

Figure 3. Cartoon sketch of Cretaceous paleogeography (from Williams and Stelck, 1975).

5.1 Upper Mannville Group

Nauss (1945) defined the Mannville Group to include units that underlie the Joli Fou Formation of the Colorado Group. A widespread disconformity separates strata from the two groups. In east-central Alberta, the Mannville Group lies above the post-Paleozoic unconformity (Glass, 1990), and is equivalent to the Blairmore Group beneath the Mill Creek Formation in southwestern Alberta (Figure 2). In southern Alberta, the Mannville Group is underlain by Jurassic rocks.

The upper Mannville Formation sediments in the south-central and southern Alberta Plains consist mainly of marine mudstones, glauconitic sandstones, and fluvial 'salt-and-pepper' sandstones. Typically, channel-cutting occurs within units of the upper Mannville reflecting transitions from fluvio-deltaic to valley-fill sandstones. In most of the southern Alberta subsurface the upper Mannville Formation is undifferentiated (cf. Hayes *et al.*, 1994), largely a consequence of the multistoried and multichanneled superposition of various sandstone units in the area. Some informal subdivision has been suggested including an upper feldspathic unit (James, 1985) and an upper lithic member (Wood, 1990; Wood and Hopkins, 1992). At the base of the upper Mannville Formation is the Glauconitic Sandstone Member (Glaister, 1959; Hopkins *et al.*, 1982; James, 1985). The upper Mannville Formation abruptly overlies the Calcareous Member (equivalent to the Ostracod Member) and is unconformably overlain by the Bow Island sandstones.

5.2 Bow Island Formation

Bow Island marine sediments interfinger with fluvial deposits of the Bruin Creek Member of the Mill Creek Formation (Blairmore Group) and with the Crowsnest volcanics (Leckie *et al.*, 1994; Leckie *et al.*, 2000; Leckie and Burden, in press; McIntosh, 1999).

As seen in core the Bow Island reservoir sandstones, occurring at the top of the Bow Island interval, are lenticular, immature "salt-and-pepper" sandstone, interbedded with abundant bentonites, and localized chert-pebble conglomerates. They are interpreted as being emplaced in estuarine to shoreline environments. Bioturbation levels are low to abundant depending upon the local energy conditions at the time of deposition. Chert-pebble conglomerates occur as lags or massive amalgamated units up to 25 m thick. Sandstones are well laminated, with common ripple, trough and planar tabular cross bedding; or, less commonly, combined-flow, flaser and/or wave ripples. Pyrite occurs as framboidal clusters and rare cubes. In the south-central Alberta subsurface siderite and ironstone concretions are common; to the north and east marine siderite hardgrounds are rare. The Bow Island Formation is dominantly marine, emplaced during minor regressions within an overall major transgression, with local channeling producing excellent reservoir rocks. Source areas were maintained by active volcanism in the southwestern part of Alberta, which was a positive feature until early Late Cretaceous time, when most of Alberta was inundated during deposition of the Westgate/Fish Scale formations. The coarse nature of the Bow Island sandstones is related to tectonism and volcanism in the Crowsnest Pass area. In southern Alberta, orange-red and brick red clasts occur in cored sediments, and these are interpreted as altered volcanic clasts.

On the geophysical logs the Bow Island is recognized by the coarsening-upward successions on the gamma ray logs. The top of the formation is abruptly overlain by the Westgate and Fish Scales formations, in an interpreted unconformable contact (Bloch et al., 1993; Glass, 1990).

5.3 Westgate Formation

The Westgate Formation is a wedge of mudstone and siltstone that thickens from 20 m in Manitoba to 120 m in northwestern Alberta. In southwestern Alberta, the Westgate is less than 20 m thick and pinches out west of the 5th Meridian (Bloch et al., 1993). The log response of the basal contact with the underlying Bow Island Formation is best expressed by a marked decrease in resistivity and an increase in sonic transit time. On our east-west cross sections, the Westgate is well expressed as a westward tapering wedge.

5.4 Fish Scales Formation

The Fish Scale Formation (Glass, 1990) is marked by an increase in radioactivity on the gamma-ray log in comparison with the underlying Westgate Formation. However, in the southern Foothills and Plains the base of the formation is difficult to determine, because of what appear to be vertical downwards and lateral gradations into the underlying Bow Island and Blairmore formations. This is particularly true west of Range 25W4 Meridian.

6 Cross sections and correlation of stratigraphic units

Petrophysical-log cross sections constructed in the study area are displayed at a vertical scale of 1:500. All cross section lines are shown on the map of Figure 1. Six of these cross sections are included with this report as enclosures (Figures 4 to 9). The other cross sections are included on a compact disc (CD), that can be purchased separately from this report. The gamma ray and resistivity curves were most useful in showing the distinctive upward coarsening log signature of the marine units of the Bow Island Formation, as opposed to the very thin interbedded sands and mudstones of the continental sequences of the Mannville Formation and the Bruin Creek Member. The small-scale (1:500) log cross sections were used to correlate the wells on one side of the depositional boundary to wells on the other side. Available core of the upper Blairmore/upper Bow Island succession was examined.

This approach found a change from dominantly marine sands and mudstones in the east to dominantly continental or deltaic deposits in the west. The transition occurs in an area spanning Ranges 26 and 27 W4 from Townships 1 to 19. This transition area approximates the north-trending Upper Blairmore paleoshoreline. In this area, Glaister (1959) used an arbitrary cutoff for the Blairmore Group that approximates the interpreted Bow Island shoreline. East of Range 25 W4 the deposits of the Bow Island Formation are predominantly marine, with a change to continental sands at the Mannville contact. There was often a distinctive, low resistivity mudstone above the Mannville Formation that helped to define the Bow Island - Mannville contact. This low resistivity silty mudstone may be equivalent to the Joli Fou mudstone.

Within Ranges 26 and 27 W4, the character of the upper Bow Island units varies from well to well. In some wells the Bow Island sediment is marine, showing a clear contrast with the

continental Blairmore sediments in the west. In other wells the Bow Island is ambiguous and the sediments are predominantly deltaic or continental. This could be consistent with an embayment of the shoreline located in this area. Within this area it is difficult to predict exactly where the Bow Island would be a marine facies or a more deltaic/continental facies. The lower Colorado shoreline shown on Figure 1 represents the proposed boundary between the upper Blairmore Group and Bow Island Formation.

West of Range 27 W4 the succession appears to be undifferentiated deltaic/continental deposits with a marine unit present between two continental sequences. The stratigraphy matches transitions observed in outcrop of the Mill Creek Formation, which consists of a basal marine Lynx Creek Member, overlying the continental Beaver Mines Formation, and which is, in turn, overlain by the continental Bruin Creek Member (Figure 2). These rocks do not represent units associated with the Joli Fou-Bow Island transgression, but rather an earlier transgression of the Lynx Creek (Leckie *et al*, 2000). Thus, this marine Blairmore unit cannot be directly correlated with the basal Bow Island sediments.

6.1 Cross section TT'

Cross section TT' (Figure 4) is the most northern cross section of this study and is running east-west through Township 19 (Figure 4). It shows the westward thinning wedges of the Bow Island and Westgate formations and the transition to the Upper Blairmore Group.

6.2 Cross section KK'

Cross section KK' (Figure 5) is through the Blairmore B Pool north of Claresholm. It shows the productive upper Blairmore sandstone and the well-defined Barons sand above it. Three cored intervals (which are described in the Appendix) are shown on the cross section. Well-defined channel sands in the upper Mannville can also be noticed.

The transition from marine environments in the upper Bow Island sand to continental environments in the upper Blairmore on the west side of R26W4 is confirmed by core from this interval in this area. For example 10-25-12-24W4 (not on cross section, but in Appendix 1.9) shows marine upper Bow Island sands, while 6-29-13-27W4 (on cross section and in Appendix 1.13) shows fluvial to estuarine upper Blairmore sands.

6.3 Cross section K2K2'

Cross section K2K2' (Figure 6) is the eastern extension of cross section KK', which ties this cross section to the DRRZD #8 (Bow Island) type well (11-31-11-10W4) and to a well used in the Atlas of the Western Canadian Sedimentary Basin (WCSB) at location 6-13-12-22W4 (Reinson *et al.*, 1994). The section nicely displays the thickening eastward wedges of the Bow Island and Westgate formations.

6.4 Cross section OO'

Cross section OO' is the southern east-west cross section (in Townships 6) and ties to the type section of the Blairmore Group exposed along Mill Creek (5-2W5; Mellon, 1967; Hein *et al.*, 2000) and to two WCSB Atlas wells. It shows the Blairmore-Bow Island transition around Range 26W4. There is still a reasonable development of the Barons sand and the Crowsnest volcanics are well-expressed on the logs (Figure 7).

6.5 Cross section XX'

Cross section XX' is the western north-south cross section. It shows the thinning wedge of the Crowsnest volcanics to the north, as a result of the larger distance from their volcanic vents near Coleman in the Crowsnest Pass (Figure 8). The Lynx Creek Member appears to be thinning in the same direction, resulting in a thinning of the whole upper Blairmore wedge. There is expression of the Barons sand along most of the cross section.

6.6 Cross section LL'

Cross section LL' (Figure 9) is the eastern north-south section and largely conforms to a WCSB Atlas cross section of the Bow Island Formation (Reinson et al., 1994; their Figure 21.8). It shows slight southward thickening wedge of Bow Island sediments, resulting from a shelf to shoreface progradation (lower Bow Island). The coastal plain wedge of Reinson et al. (1994) is possibly time equivalent to the Crowsnest volcanics and contains many bentonites. These bentonites still need to be dated to confirm this relationship (the Crowsnest volcanics are around 100 Ma, see above).

7 Core descriptions

A representative suite of cores from the Granum area shows typical facies and interpreted depositional environments for the upper Bow Island Formation in the southwestern Alberta subsurface (Figure 1). Of these environments, one is mainly fluvial, others show mixed fluvial and shallow marine influences, and one is dominantly marine.

7.1 Core of 06-30-11-25W4

At the base of the cored interval in this well (Figure 10) the Bow Island sands are abruptly (? unconformably) underlain by deeper-water marine mudstones, which are pyritic and bioturbated. Bow Island core from the 06-30-11-25W4 well consists of mainly fluvial successions overlain by tidal channel and shoreface deposits, capped by a rooted paleosol at the top of the sequence. Abruptly overlying the Bow Island sands is a medium to dark grey, bioturbated sandy mudstone that underlies the Base of the Fish Scale Marker.

The fluvial sediments show fining upward successions, with pronounced planar tabular and low-angle cross bedding with apparently unimodal paleoflow patterns. Thin quartz pebble lags occur along cross beds as thin stringers. The occurrence of rare horizontal *Planolites* burrows does not

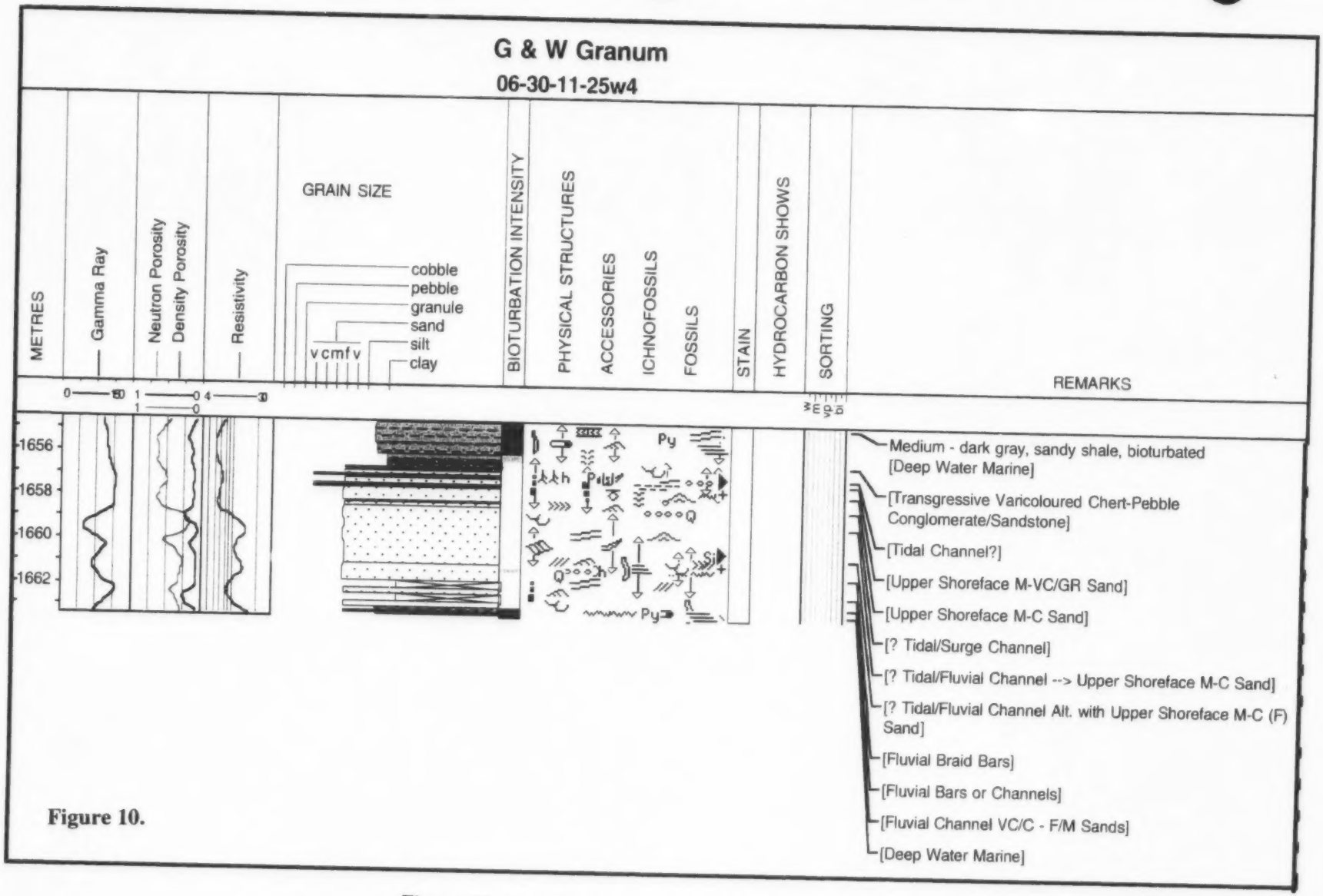

Figure 10.

Figure 10. Core description of well 06-30-11-25W4.

discount a fluvial interpretation. Upsection, the sandstones show a more variable, approximately bimodal, 180 degree alternation of cross bed directions, interpreted as herringbone cross bedding, along with wave and flaser ripples, pebble lags, parallel and low-angle cross bedding, internal truncations and scour surfaces. These sediments are interpreted as tidal-surge channel and upper shoreface deposits. The top of the shoreface succession is marked by a rooted paleosol. In the overlying mudstone is a thin, mainly bioturbated varicoloured chert-pebble conglomerate, interpreted as a transgressive lag. Successive mudstones are medium to dark grey, bioturbated, with a more diverse ichnofauna, rare rippled and parallel to low-angle cross bedded very fine sandstone/siltstone interbeds, interpreted as a deeper water marine succession.

7.2 Core of 16-18-11-25W4

At the base of the cored interval in this well (Figure 11) the Bow Island consists of fluvial conglomerate overlain by shoreface deposits, capped by a bioturbated transgressive conglomerate lag. At the top of the Bow Island is a medium to dark gray, bioturbated, bentonitic sandy silty mudstone of the Westgate Formation that underlies the Base of the Fish Scale Marker.

The fluvial conglomerate shows fining upward successions that are internally horizontally stratified, marked by thin quartz, chert and lithic pebble stringers. Upsection the sandstones show convolute lamination, parallel and low-angle cross bedding, with internal truncations, local granule lags and scour surfaces. These sediments are interpreted as lower to middle and upper shoreface sandstones. The top of the shoreface unit is marked by a transgressive lag, comprising chert and lithic pebbles dispersed within deeper water marine mudstone. This deeper marine unit is commonly burrowed, with horizontal *Planolites*, oblique burrows, and u-shaped *Diplocriterion*. Successive mudstones are medium to dark gray, slightly bentonitic, moderately bioturbated, and interpreted as a deeper water marine unit.

7.3 Core of 10-24-11-26W4

At the base of the cored interval in this well (Figure 12) the Bow Island consists of upper shoreface units, capped by a bioturbated transgressive conglomerate lag. Abruptly overlying the Bow Island is a medium to dark gray, bioturbated, sandy of the Westgate Formation.

The upper shoreface sandstones are medium to coarse grained, with horizontal stratification, low-angle cross bedding, bimodal cross bed directions, internal truncations, ball-and-pillow structures, convolute lamination, escape burrows, and dispersed pebbles and granules. The top of the shoreface units is marked by a transgressive lag, comprising quartz, chert and lithic pebbles dispersed within bioturbated marine mudstone. Successive mudstones are medium to dark gray, slightly sandy, and moderately bioturbated, interpreted as a deeper water marine succession.

7.4 Core of 07-25-11-26W4

At the base of the cored interval in this well (Figure 13) the Bow Island consists of an upper shoreface succession capped by fluvial and bioturbated transgressive conglomerate lags. Abruptly overlying the Bow Island is a medium to dark gray, bentonitic, siltstone and sandy silty

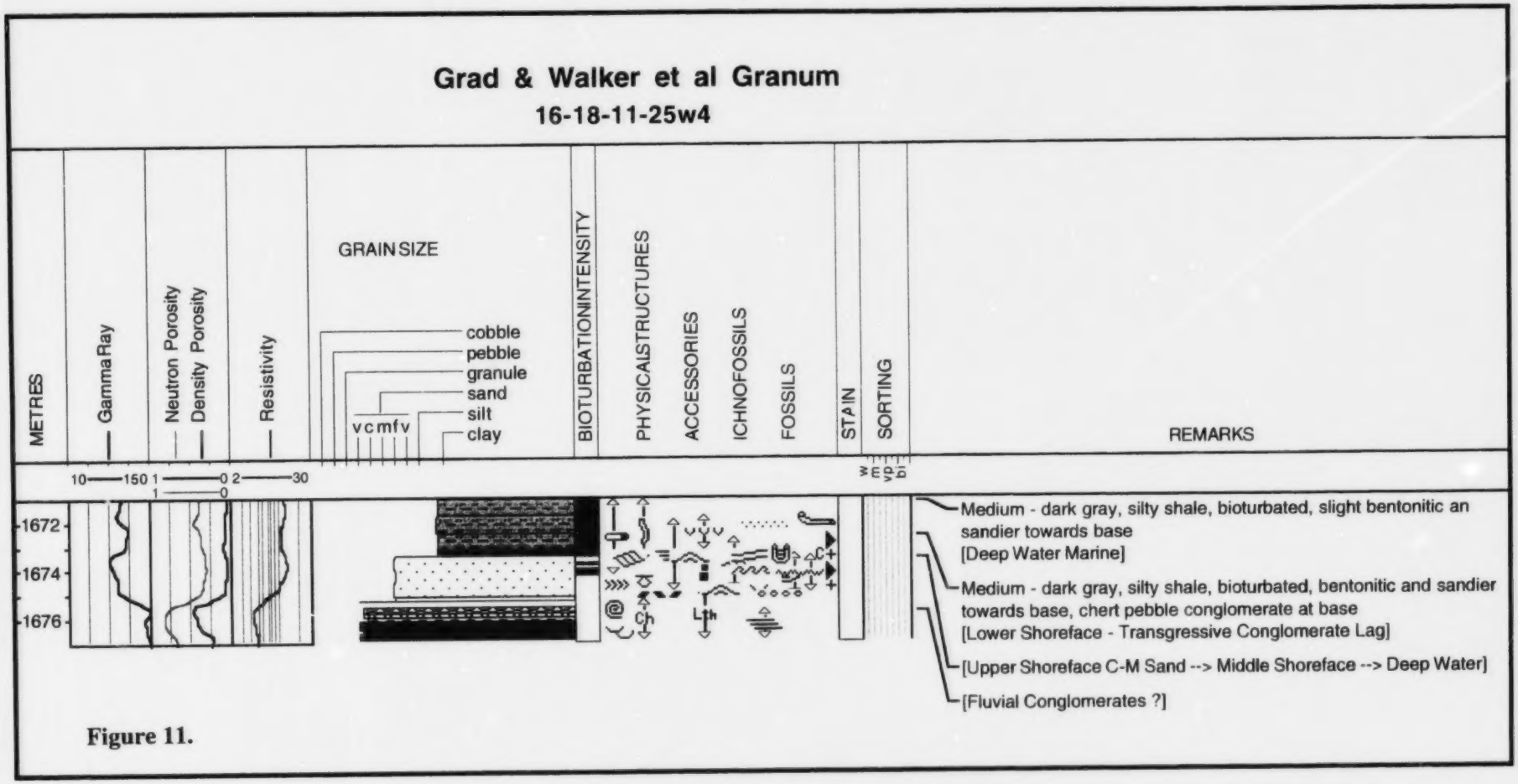

Figure 11. Core description of well 16-18-11-25W4.

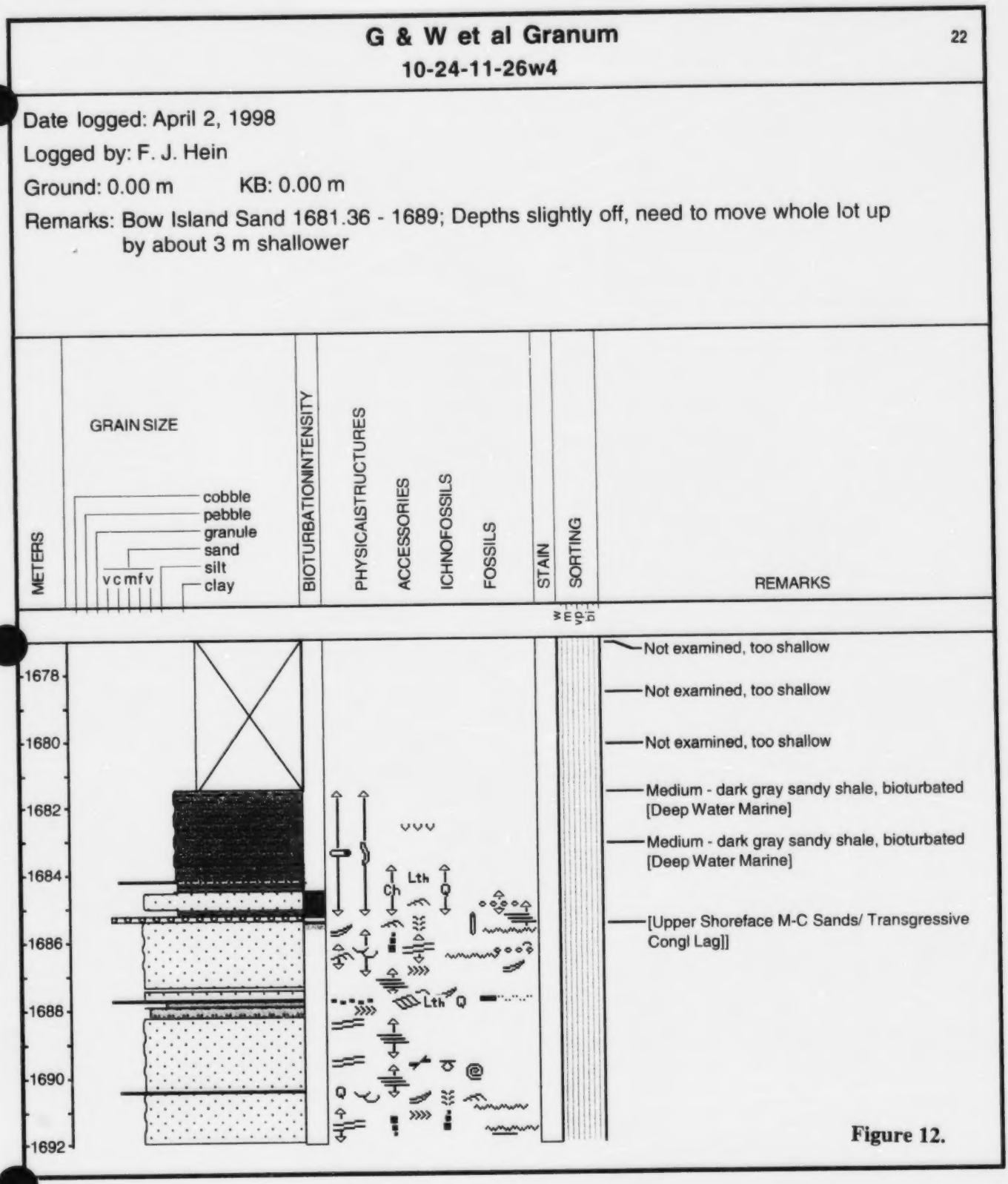

Figure 12. Core description of well 10-24-11-26W4.

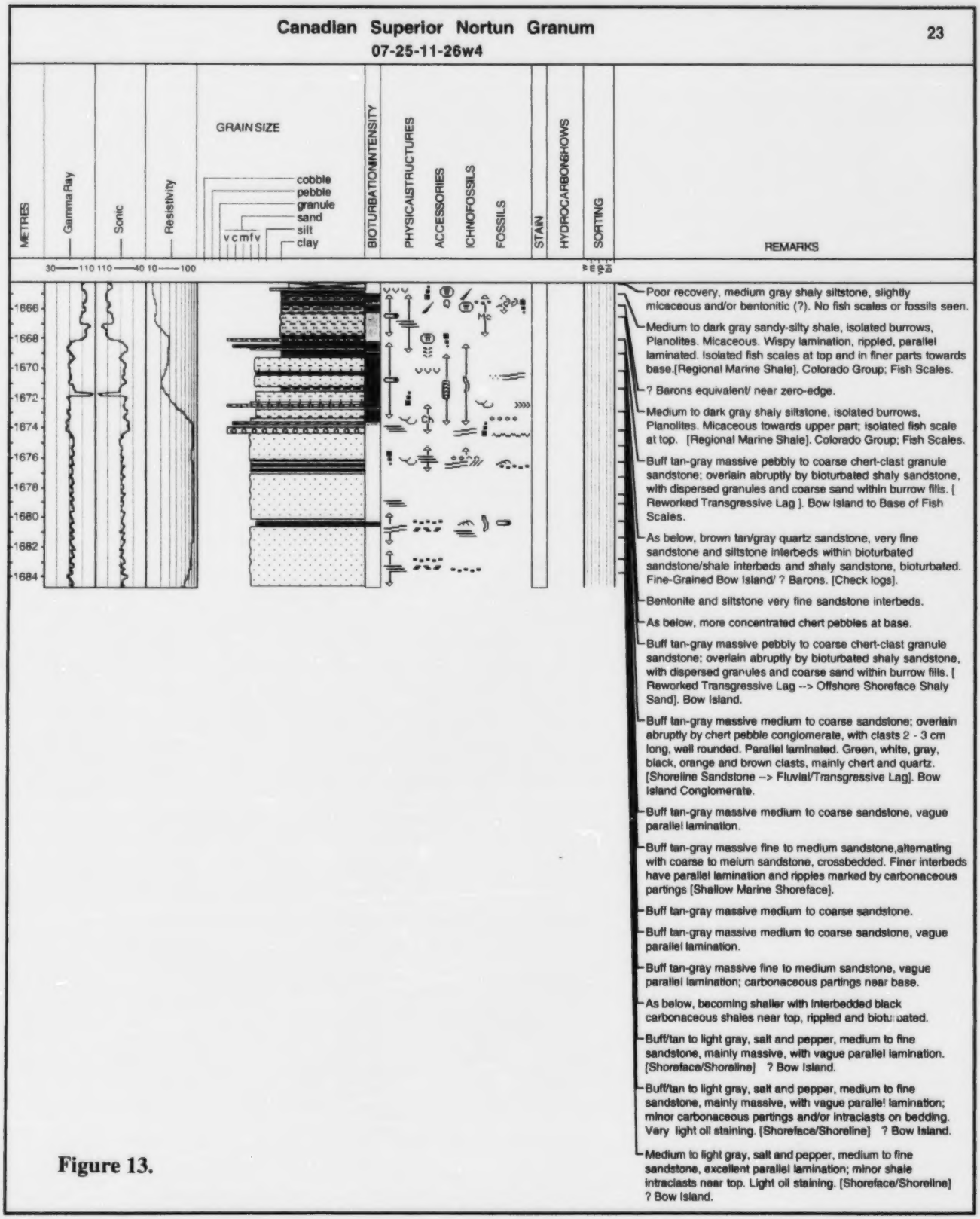
Canadian Superior Nortun Granum
07-25-11-26w4
23
METRES
Gamma Ray
Sonic
Resistivity
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
STAIN
HYDROCARBON SHOWS
SORTING
REMARKS
30 110 110 40 10 100
1666
1668
1670
1672
1674
1676
1678
1680
1682
1684
Poor recovery, medium gray shaly siltstone, slightly micaceous and/or bentonitic (?). No fish scales or fossils seen.
Medium to dark gray sandy-silty shale, isolated burrows, Planolites. Micaceous. Wispy lamination, rippled, parallel laminated. Isolated fish scales at top and in finer parts towards base.[Regional Marine Shale]. Colorado Group; Fish Scales.
? Barons equivalent/ near zero-edge.
Medium to dark gray shaly siltstone, isolated burrows, Planolites. Micaceous towards upper part; isolated fish scale at top. [Regional Marine Shale]. Colorado Group; Fish Scales.
Buff tan-gray massive pebbly to coarse chert-clast granule sandstone; overlain abruptly by bioturbated shaly sandstone, with dispersed granules and coarse sand within burrow fills. [Reworked Transgressive Lag]. Bow Island to Base of Fish Scales.
As below, brown tan/gray quartz sandstone, very fine sandstone and siltstone interbeds within bioturbated sandstone/shale interbeds and shaly sandstone, bioturbated. Fine-Grained Bow Island/ ? Barons. [Check logs].
Bentonite and siltstone very fine sandstone interbeds.
As below, more concentrated chert pebbles at base.
Buff tan-gray massive pebbly to coarse chert-clast granule sandstone; overlain abruptly by bioturbated shaly sandstone, with dispersed granules and coarse sand within burrow fills. [Reworked Transgressive Lag --> Offshore Shoreface Shaly Sand]. Bow Island.
Buff tan-gray massive medium to coarse sandstone; overlain abruptly by chert pebble conglomerate, with clasts 2 - 3 cm long, well rounded. Parallel laminated. Green, white, gray, black, orange and brown clasts, mainly chert and quartz. [Shoreline Sandstone --> Fluvial/Transgressive Lag]. Bow Island Conglomerate.
Buff tan-gray massive medium to coarse sandstone, vague parallel lamination.
Buff tan-gray massive fine to medium sandstone,alternating with coarse to melum sandstone, crossbedded. Finer interbeds have parallel lamination and ripples marked by carbonaceous partings [Shallow Marine Shoreface].
Buff tan-gray massive medium to coarse sandstone.
Buff tan-gray massive medium to coarse sandstone, vague parallel lamination.
Buff tan-gray massive fine to medium sandstone, vague parallel lamination; carbonaceous partings near base.
As below, becoming shaller with interbedded black carbonaceous shales near top, rippled and biotu bated.
Buff/tan to light gray, salt and pepper, medium to fine sandstone, mainly massive, with vague parallel lamination. [Shoreface/Shoreline] ? Bow Island.
Buff/tan to light gray, salt and pepper, medium to fine sandstone, mainly massive, with vague parallel lamination; minor carbonaceous partings and/or intraclasts on bedding. Very light oil staining. [Shoreface/Shoreline] ? Bow Island.
Medium to light gray, salt and pepper, medium to fine sandstone, excellent parallel lamination; minor shale intraclasts near top. Light oil staining. [Shoreface/Shoreline] ? Bow Island.

Figure 13.

Figure 13. Core description of well 07-25-11-26W4.

mudstone of the Westgate Formation.

The upper shoreface sandstones are medium to coarse grained, with horizontal and low-angle stratification, apparently opposing paleocurrent directions, internal scour surfaces, ball-and-pillow structures, convolute lamination, dispersed pebbles and granules, and oblique burrows. The top of the shoreface units is marked by a series of transgressive lags, comprising quartz, chert and lithic pebbles dispersed within deeper water marine mudstone. The deeper water marine mudstone is extensively burrowed, with horizontal *Planolites*, vertical-escape burrows, u-shaped *Diplocriterion*, and oblique forms. Successive mudstones are medium to dark gray, slightly micaceous or bentonitic, with abundant fish scales, interpreted as a deeper water marine succession.

7.5 Core of 11-33-11-26W4

At the base of the cored interval in this well (Figure 14) the sediment consists of sandy mudstone with thin discontinuous sandstone interlaminae, that are rippled or show low-angle stratification, with moderate degrees of bioturbation. This part of the succession is interpreted as a deeper water marine unit. Abruptly overlying these sandy mudstones are lower shoreface units of the Bow Island Formation that, in turn, are abruptly overlain by the Westgate Formation.

The Bow Island comprises lower shoreface units, consisting of medium to fine grained sandstones, with convolute lamination, burrows, and alternating with mudstone. Partially preserved ripples occur in beds where bioturbation is reduced. Well-defined burrows include the horizontal *Planolites* and the larger *Paleophycus*, u-shaped *Diplocriterion*, and possible *Chondrites*. The top of the shoreface succession is marked by a transgressive lag, comprising quartz, chert and lithic pebbles dispersed within finer marine mudstone. The overlying Fish Scale Formation consists of silty mudstone with abundant fish scales and a prominent bentonite marker bed. Sedimentary structures within the coarser siltstone interbeds within the Fish Scales include parallel lamination, current and wave ripple cross bedding.

8 Conclusions

A change from dominantly marine Bow Island sands and mudstones to continental or deltaic Upper Blairmore (Bruin Creek Member) occurs across Ranges 26 and 27 W4 in the study area. This can be envisioned as an ancient shoreline with common embayments (Figure 1). Some wells drilled in the area will encounter marine Bow Island units, others will encounter continental successions.

West of Range 27 W4 the Bow Island succession is predominantly continental and is interpreted to be the facies equivalent of the Mill Creek and Crowsnest formations. In the region east of Range 25 W4, from Townships 1 through 19, Mannville-Bow Island terminology can be used. In areas west of Range 27 W4, near the limit of the deformed belt, Blairmore terminology can be used.

In the transition area from Range 26 to 27 W4, where both the Bow Island marine and the Mill Creek continental facies are found, both terminologies can be employed, depending upon which

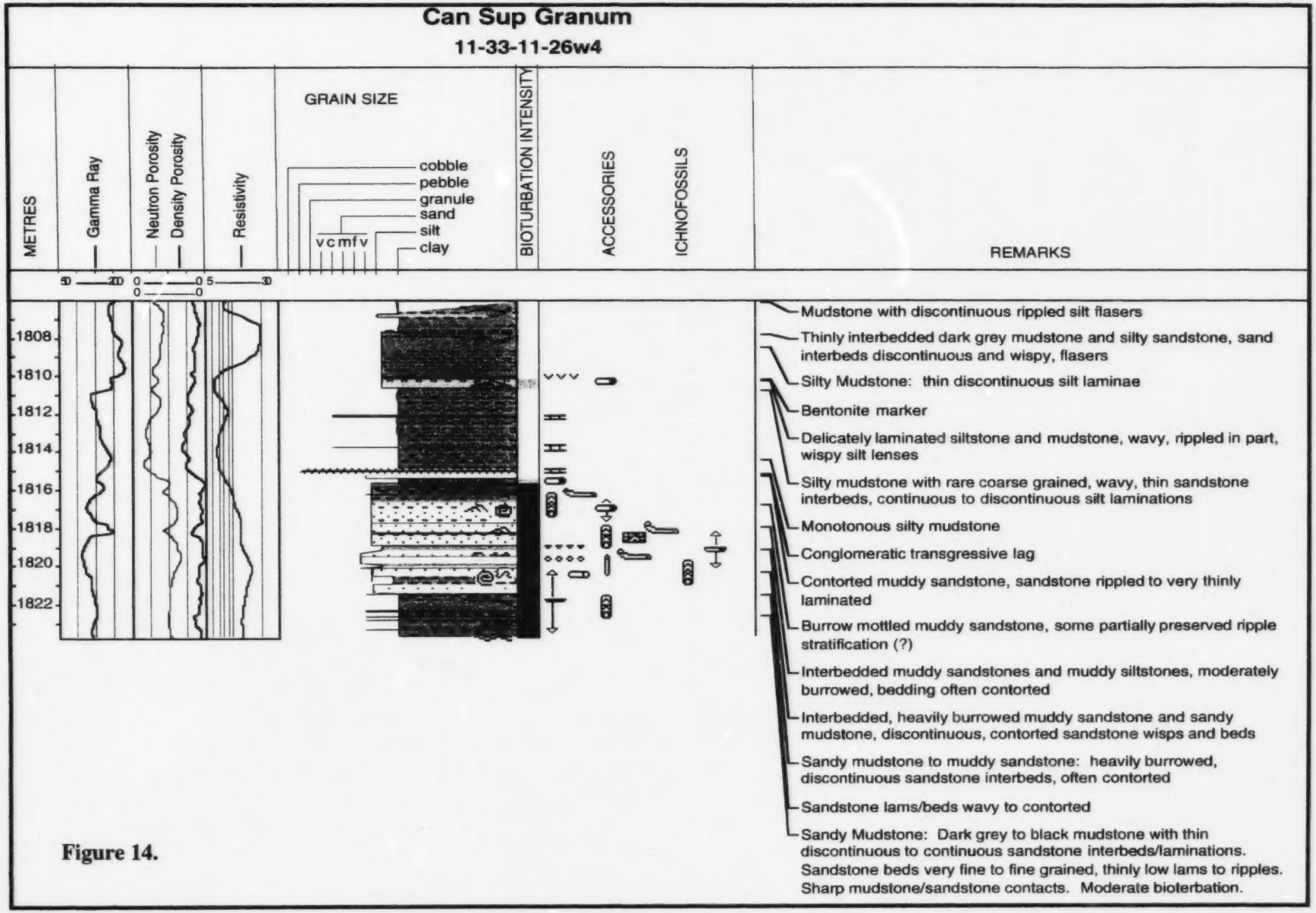
Can Sup Granum
11-33-11-26w4
METRES
Gamma Ray
Neutron Porosity
Density Porosity
Resistivity
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
v c m f v
BIOTURBATION INTENSITY
ACCESSORIES
ICHNOFOSSILS
REMARKS
1808
1810
1812
1814
1816
1818
1820
1822
Mudstone with discontinuous rippled silt flasers
Thinly interbedded dark grey mudstone and silty sandstone, sand interbeds discontinuous and wispy, flasers
Silty Mudstone: thin discontinuous silt laminae
Bentonite marker
Delicately laminated siltstone and mudstone, wavy, rippled in part, wispy silt lenses
Silty mudstone with rare coarse grained, wavy, thin sandstone interbeds, continuous to discontinuous silt laminations
Monotonous silty mudstone
Conglomeratic transgressive lag
Contorted muddy sandstone, sandstone rippled to very thinly laminated
Burrow mottled muddy sandstone, some partially preserved ripple stratification (?)
Interbedded muddy sandstones and muddy siltstones, moderately burrowed, bedding often contorted
Interbedded, heavily burrowed muddy sandstone and sandy mudstone, discontinuous, contorted sandstone wisps and beds
Sandy mudstone to muddy sandstone: heavily burrowed, discontinuous sandstone interbeds, often contorted
Sandstone lams/beds wavy to contorted
Sandy Mudstone: Dark grey to black mudstone with thin discontinuous to continuous sandstone interbeds/laminations. Sandstone beds very fine to fine grained, thinly low lams to ripples. Sharp mudstone/sandstone contacts. Moderate bioterbation.
Figure 14.

Figure 14. Core description of well 11-33-11-26W4.

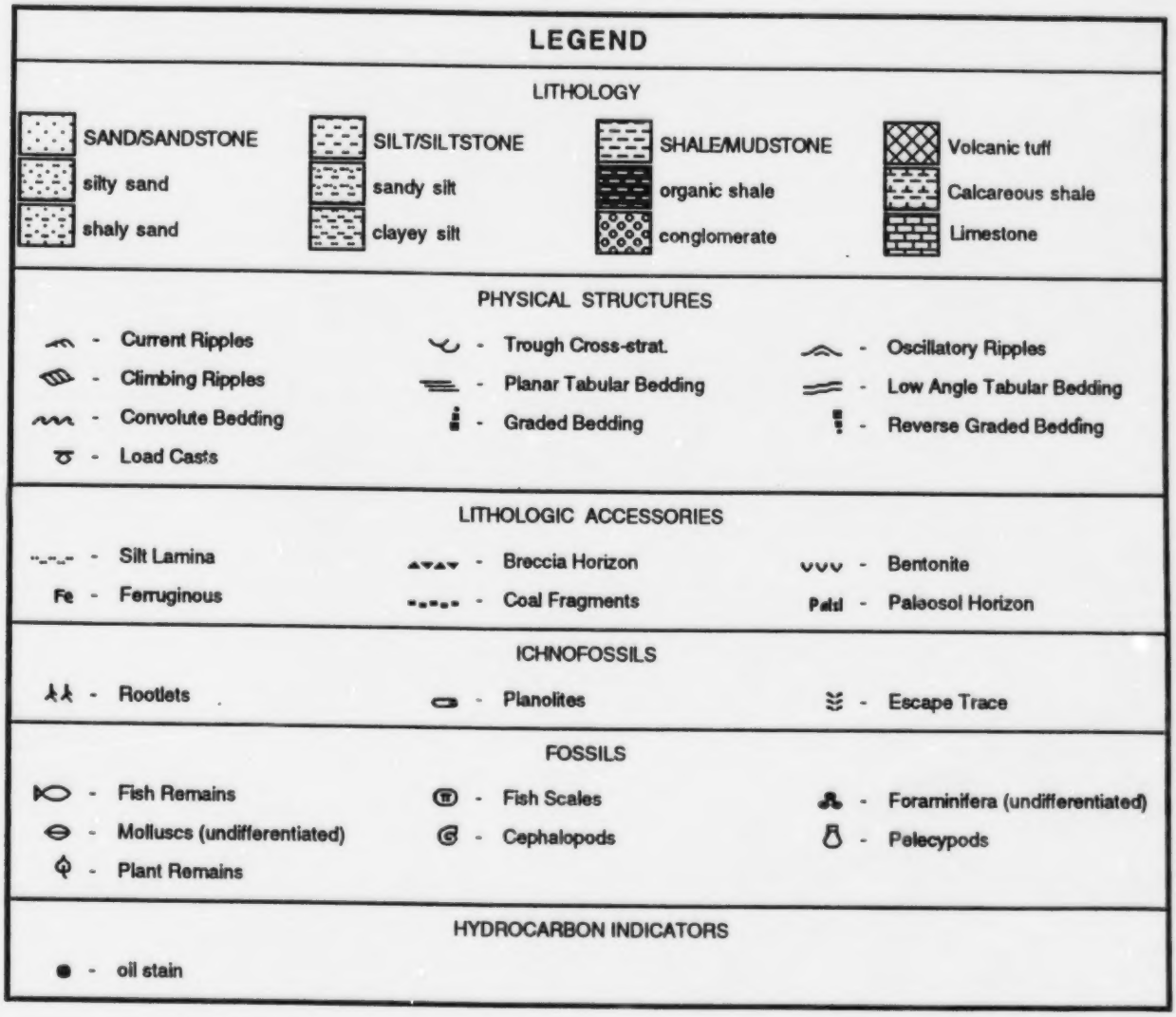

Figure 15. Legend for core descriptions used in this report.

units are encountered. Care must be taken in this stratigraphic interpretation to be sure that the Lynx Creek marine units of the Blairmore Group are not mistakenly interpreted as Bow Island marine successions.

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Appendix 1.1

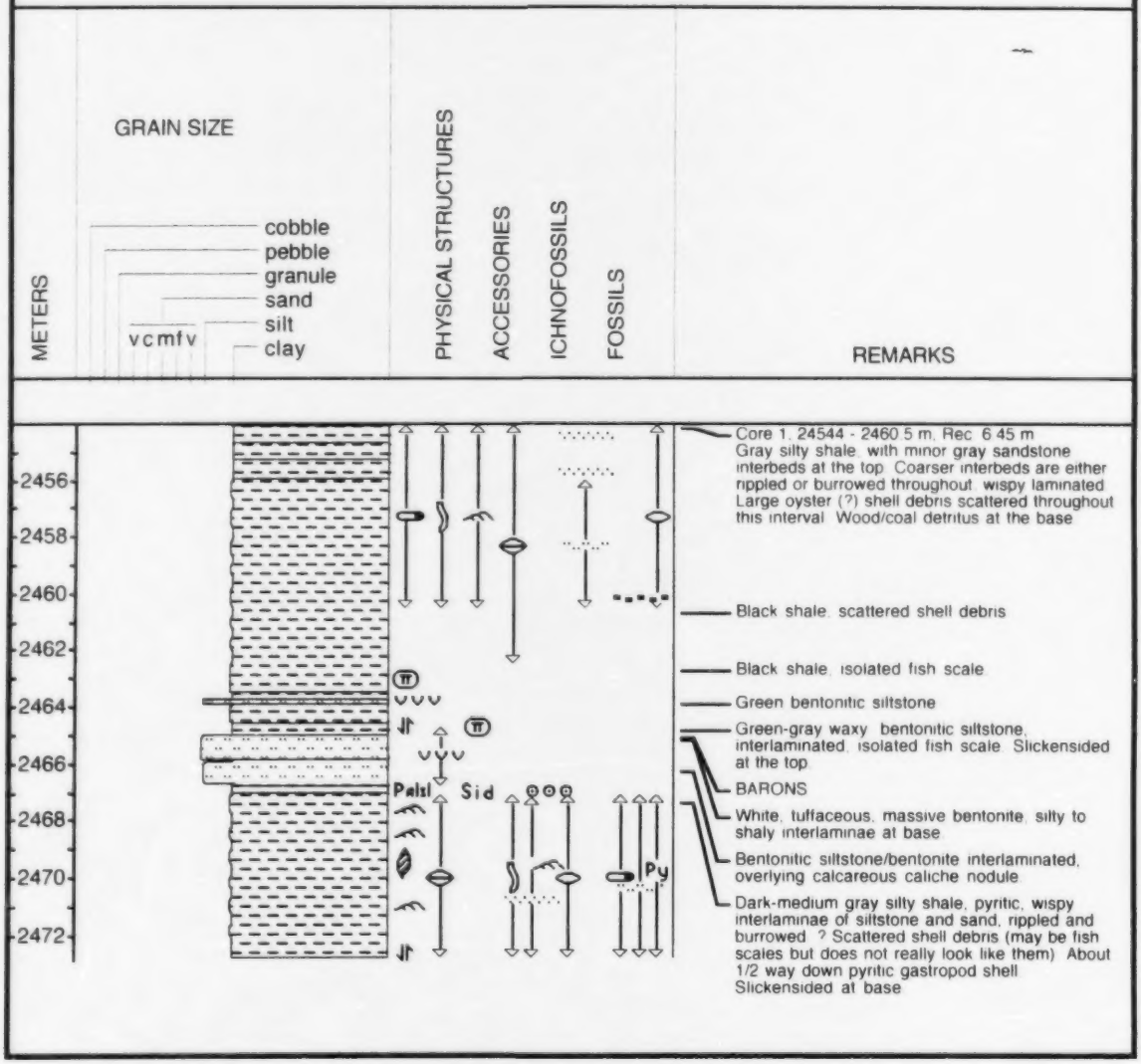
UPRI et al Glenwood

15-10-05-27w4

Date logged: April 20, 1998

Logged by: F. J. Hein

Remarks: Barons: thick massive bentonitic silt overlying a calcareous nodule, probably caliche. Both between dark gray to black shales, silty; above Cretaceous, below Mannville/Blairmore Grp. black shales.


METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vcmfv
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
2456
2458
2460
2462
2464
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2468
2470
2472
Palsi
Sid
Py
Core 1, 2454.4 - 2460.5 m, Rec. 6.45 m
Gray silty shale, with minor gray sandstone interbeds at the top. Coarser interbeds are either rippled or burrowed throughout, wispy laminated. Large oyster (?) shell debris scattered throughout this interval. Wood/coal detritus at the base
Black shale, scattered shell debris
Black shale, isolated fish scale
Green bentonitic siltstone
Green-gray waxy, bentonitic siltstone, interlaminated, isolated fish scale. Slickensided at the top
BARONS
White, tuffaceous, massive bentonite, silty to shaly interlaminae at base
Bentonitic siltstone/bentonite interlaminated, overlying calcareous caliche nodule
Dark-medium gray silty shale, pyritic, wispy interlaminae of siltstone and sand, rippled and burrowed. ? Scattered shell debris (may be fish scales but does not really look like them). About 1/2 way down pyritic gastropod shell. Slickensided at base

Appendix 1.2

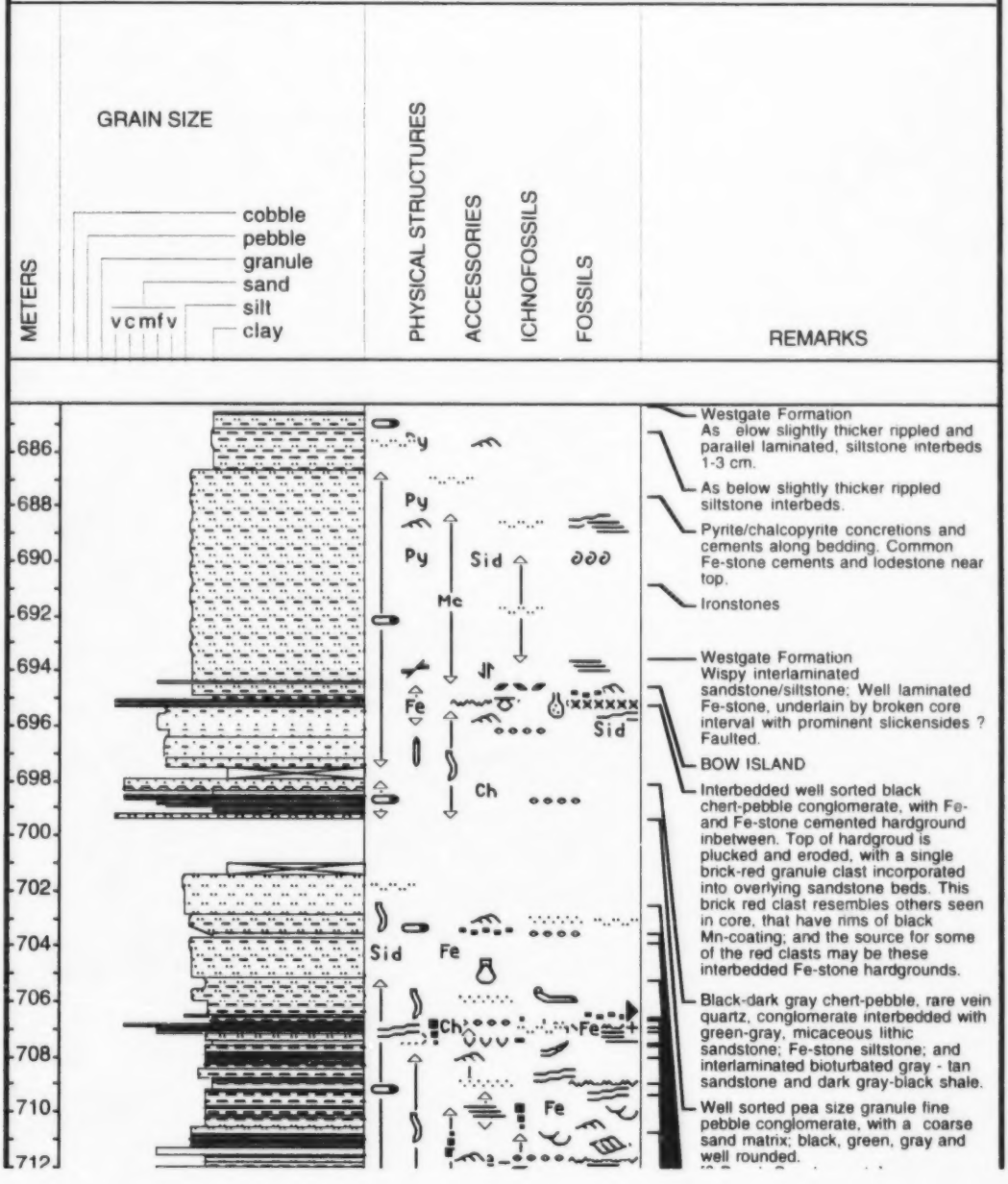
Imp Med Chin Coulee

10-10-08-17w4

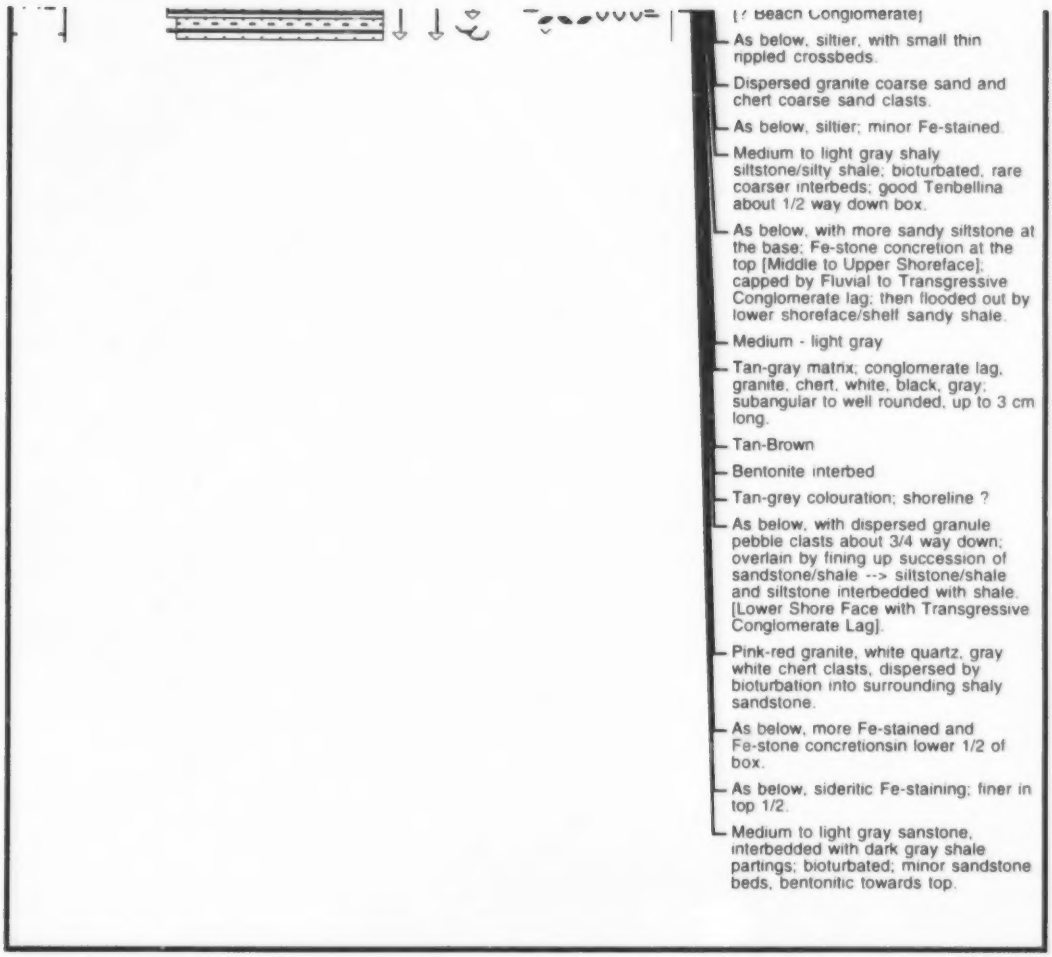
Date logged: January 28, 1998

Logged by: F. J. Hein

Remarks: Fine grained Bow Island -- Westgate Fm shales.


METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
686
688
690
692
694
696
698
700
702
704
706
708
710
712
Py
Sid
Mc
Fe
Ch
Westgate Formation
As elow slightly thicker rippled and parallel laminated, siltstone interbeds 1-3 cm.
As below slightly thicker rippled siltstone interbeds.
Pyrite/chalcopyrite concretions and cements along bedding. Common Fe-stone cements and lodestone near top.
Ironstones
Westgate Formation
Wispy interlaminated sandstone/siltstone; Well laminated Fe-stone, underlain by broken core interval with prominent slickensides ? Faulted.
BOW ISLAND
Interbedded well sorted black chert-pebble conglomerate, with Fe- and Fe-stone cemented hardground inbetween. Top of hardgroud is plucked and eroded, with a single brick-red granule clast incorporated into overlying sandstone beds. This brick red clast resembles others seen in core, that have rims of black Mn-coating; and the source for some of the red clasts may be these interbedded Fe-stone hardgrounds.
Black-dark gray chert-pebble, rare vein quartz, conglomerate interbedded with green-gray, micaceous lithic sandstone; Fe-stone siltstone; and interlaminated bioturbated gray - tan sandstone and dark gray-black shale.
Well sorted pea size granule fine pebble conglomerate, with a coarse sand matrix; black, green, gray and well rounded.

Appendix 1.2 (continued)


[? Beach Conglomerate]
As below, siltier, with small thin rippled crossbeds.
Dispersed granite coarse sand and chert coarse sand clasts.
As below, siltier; minor Fe-stained.
Medium to light gray shaly siltstone/silty shale; bioturbated, rare coarser interbeds; good Tenbellina about 1/2 way down box.
As below, with more sandy siltstone at the base; Fe-stone concretion at the top [Middle to Upper Shoreface]; capped by Fluvial to Transgressive Conglomerate lag; then flooded out by lower shoreface/shelf sandy shale.
Medium - light gray
Tan-gray matrix; conglomerate lag, granite, chert, white, black, gray; subangular to well rounded, up to 3 cm long.
Tan-Brown
Bentonite interbed
Tan-grey colouration; shoreline ?
As below, with dispersed granule pebble clasts about 3/4 way down; overlain by fining up succession of sandstone/shale --> siltstone/shale and siltstone interbedded with shale. [Lower Shore Face with Transgressive Conglomerate Lag].
Pink-red granite, white quartz, gray white chert clasts, dispersed by bioturbation into surrounding shaly sandstone.
As below, more Fe-stained and Fe-stone concretionsin lower 1/2 of box.
As below, sideritic Fe-staining; finer in top 1/2.
Medium to light gray sanstone, interbedded with dark gray shale partings; bioturbated; minor sandstone beds, bentonitic towards top.

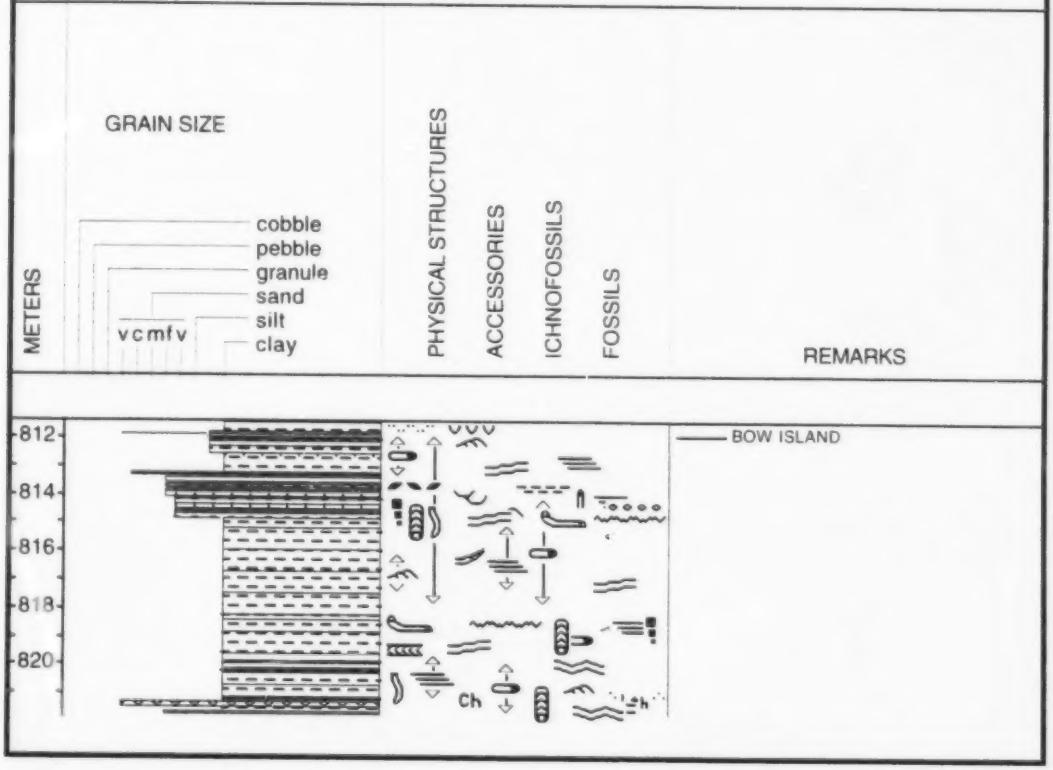
Can Hunter POP Coaldale

10-01-08-20w4

Date logged: January 28, 1998

Logged by: F. J. Hein

Remarks: Top of Bow Island Fm.



Appendix 1.4

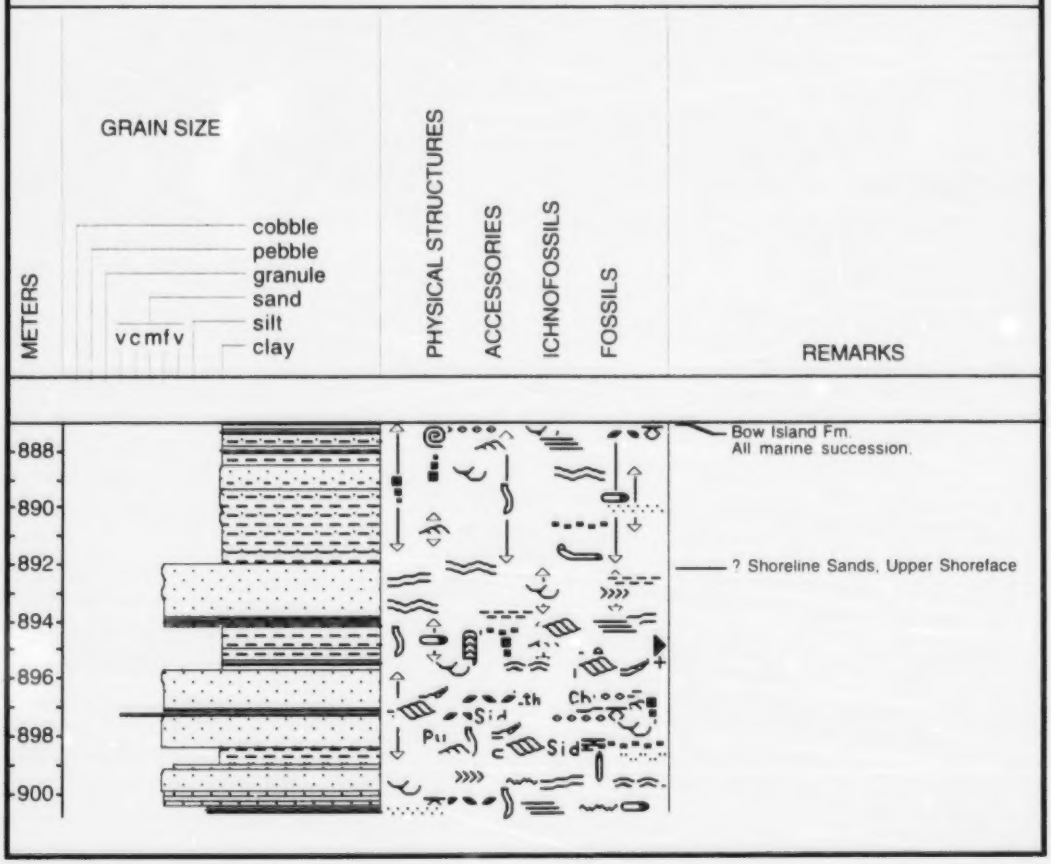
Can Hunter et al Leth

06-14-08-21w4

Date logged: January 28, 1998

Logged by: F. J. Hein

Remarks: Type Bow Island well from atlas, but only has core from 2910 - 2955 ft (807-901 m).



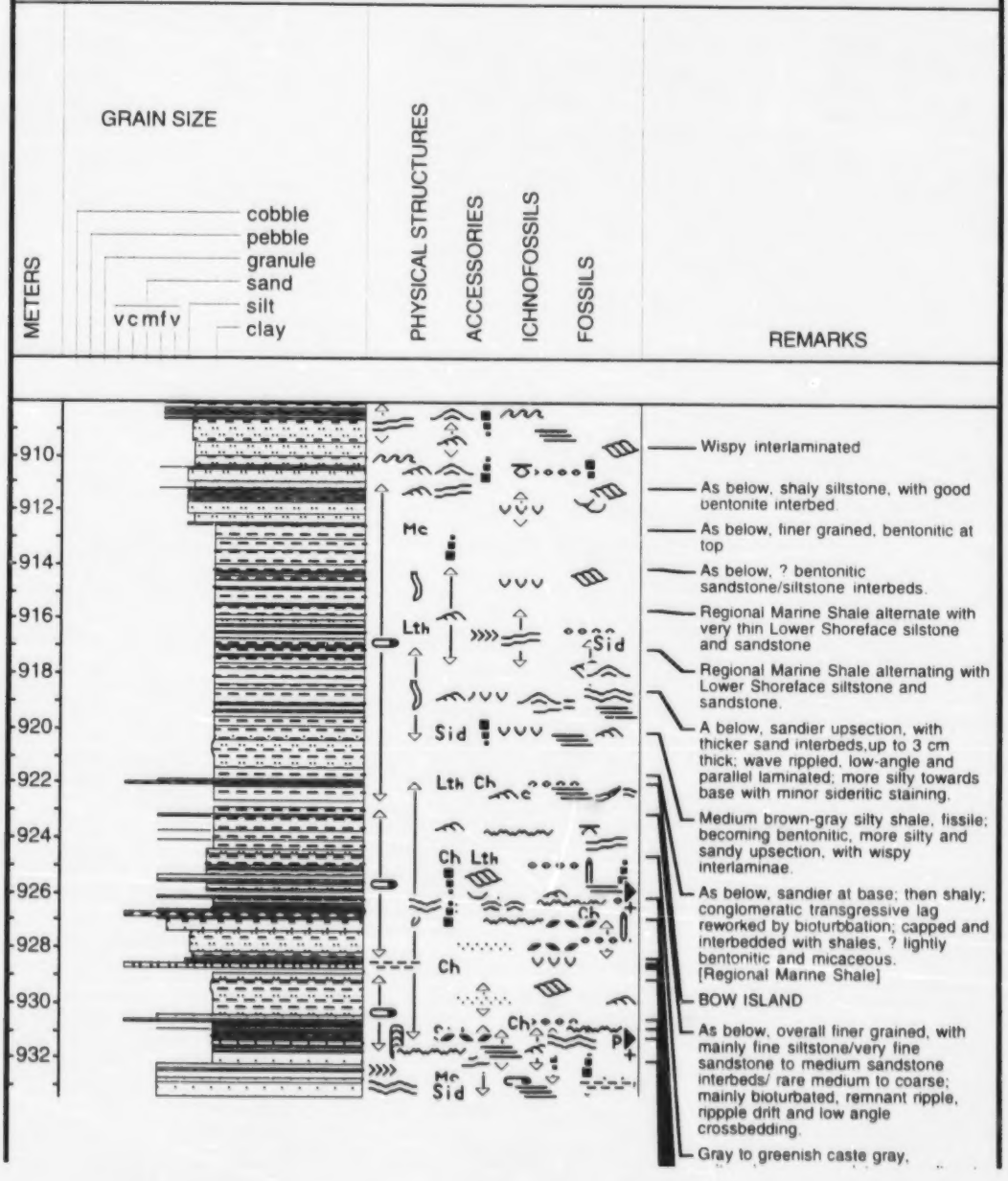
Can Hunter PCP Leth

11-28-09-21w4

Date logged: January 26, 1998

Logged by: F. J. Hein

Remarks: Thick Colorado Shale (with bentonites), Bow Island and Westgate Fms. Tops from logs are: Second White Specks 821 m; Base of Fish Scales 908 m; Bow Island 921 m.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GRAIN SIZE
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pebble
granule
sand
silt
clay
vcmfv
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
910
912
914
916
918
920
922
924
926
928
930
932
Mc
Lth
Sid
Lth Ch
Ch Lth
Ch
Mc Sid
Wispy interlaminated
As below, shaly siltstone, with good bentonite interbed
As below, finer grained, bentonitic at top
As below, ? bentonitic sandstone/siltstone interbeds.
Regional Marine Shale alternate with very thin Lower Shoreface silstone and sandstone
Regional Marine Shale alternating with Lower Shoreface siltstone and sandstone.
A below, sandier upsection, with thicker sand interbeds,up to 3 cm thick; wave rippled, low-angle and parallel laminated; more silty towards base with minor sideritic staining.
Medium brown-gray silty shale, fissile; becoming bentonitic, more silty and sandy upsection, with wispy interlaminae.
As below, sandier at base; then shaly; conglomeratic transgressive lag reworked by bioturbation; capped and interbedded with shales, ? lightly bentonitic and micaceous. [Regional Marine Shale]
BOW ISLAND
As below, overall finer grained, with mainly fine siltstone/very fine sandstone to medium sandstone interbeds/ rare medium to coarse; mainly bioturbated, remnant ripple, ripple drift and low angle crossbedding.
Gray to greenish caste gray.

Appendix 1.5 (continued)

salt-and-pepper sandstone, medium to coarse very coarse ta the base; interbedded with sandy shale; bioturbated thoruvhout,, becoming granule dispersed in upper half of core, mixed in by bioturbation.

- Matrix supported, tan,gray and ochre chert-granule and siltstone clasts up to 0.3 cm long, well rounded; dispersed within finer clayey matrix by bioturbation.
- Transgressive conglomerate lags
- Matrix supported, tan,gray and ochre siltstone and clay clasts up to 0.5 cm long, well rounded; dispersed within finer clayey matrix by bioturbation.
- Bentonitic siltstone
- Reworked and interbedded bentonite and gray shale.
- Matrix supported, chert and brick red conglomerate, clasts up to 1.5 cm long, well rounded; dispersed within finer clayey matrix by bioturbation.
- Gray silty clay with tan/ochre siltstone, and gray very fine sandstone/siltstone interbeds; bioturbated. Ripple, climbing ripple remnants. Pyritic or sideritic nodules after intraclasts about 1/2 way up box. Dispersed granule and fine pebble clasts top 0.15 m, same lithology of brick red clasts and cherts as below; well rounded and mixed in by bioturbation.
- Medium gray, bioturbated chert pebble conglomerate, grading into bioturbated chert-pebble granule sandstone --> shaly sandstone. Wide variety of pebble clasts, including red brick colour (similar to red specks), white, gray, tan, orange and green; mainly well rounded and dominantly chert. Towards base montmorilonitic swelling clay bioturbated interlaminae.
- Grey-light grey well sorted fine/very fine to medium mainly quartz sandstone; excellent parallel, ripple drift and wave ? rippled crossbeds; interbedded with finer dark gray shales, delicately laminated. Finer interbedded shale and silty shale is micaceous and bioturbated. [Lower - Medium Energy Shoreface]
- Rounded tan and pink-tan claystone/siltstone intraclasts, up to 0.7 cm long
- Grey-light grey well sorted fine/very fine to medium mainly quartz sandstone; excellent parallel, low angle and rippled crossbeds; interbedded with finer dark gray shaly sandstone, delicately laminated. Finer interbedded shale and silty shale is micaceous and bioturbated. [Mainly High Energy Shoreface]

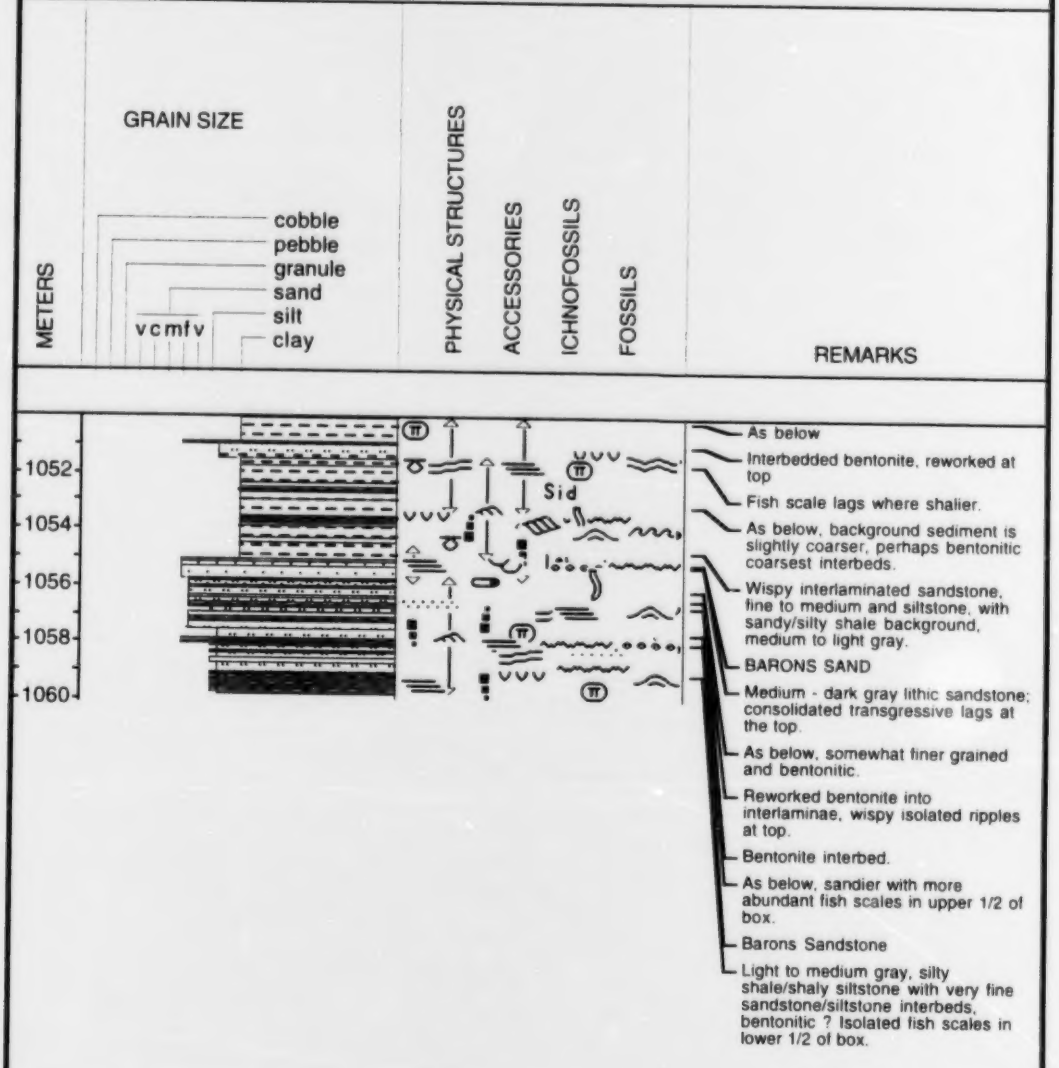
C. S. et al KEHO (1)

06-13-12-22w4

Date logged: January 26, 1998

Logged by: F. J. Hein

Remarks: Upper interval of this well, logged within what has been picked as Barons Sandstone. Top log picks are: Barons 1042; Base of Fish Scales 1060 m; Bow Island 1076 m ; Mannville 1204 m. On Atlas Section JJ'.



Appendix 1.7

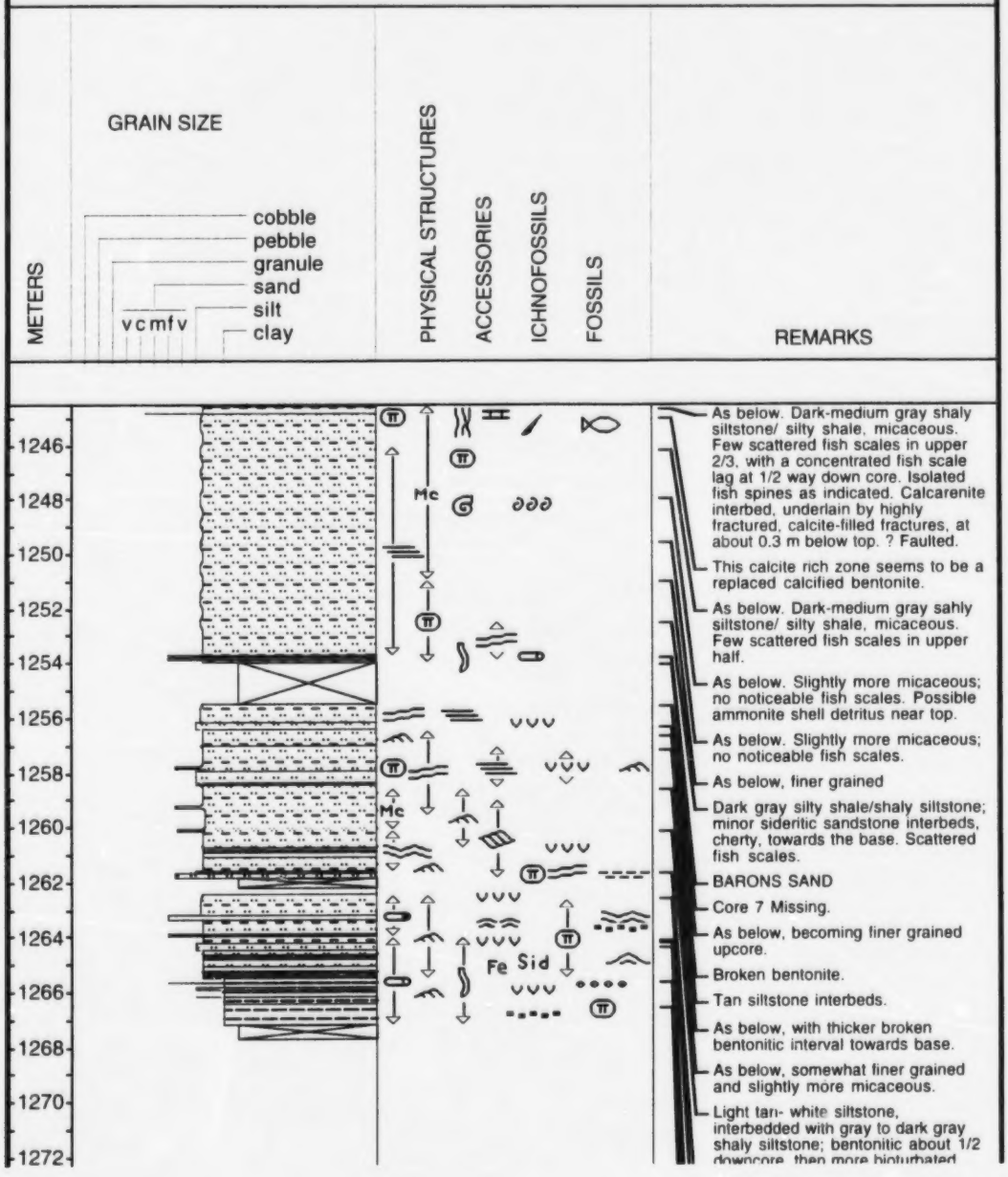
Smith Hunter Gallita Barons 1

08-15-12-23w4

Date logged: January 7, 1998

Logged by: F. J. Hein

Remarks: Core at AEUB Core Lab is in 7 broken intervals from 4083 to 6937 ft (1244 m - 2114 m). Top 2nd White Specks is at 3818.10 ft (1164 m) (not cored), and top of Jurassic is at 5180.37 ft (1579 m). Logged from the top of the cored interval downsection. Core descriptions of cores 1 & 2 given.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sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
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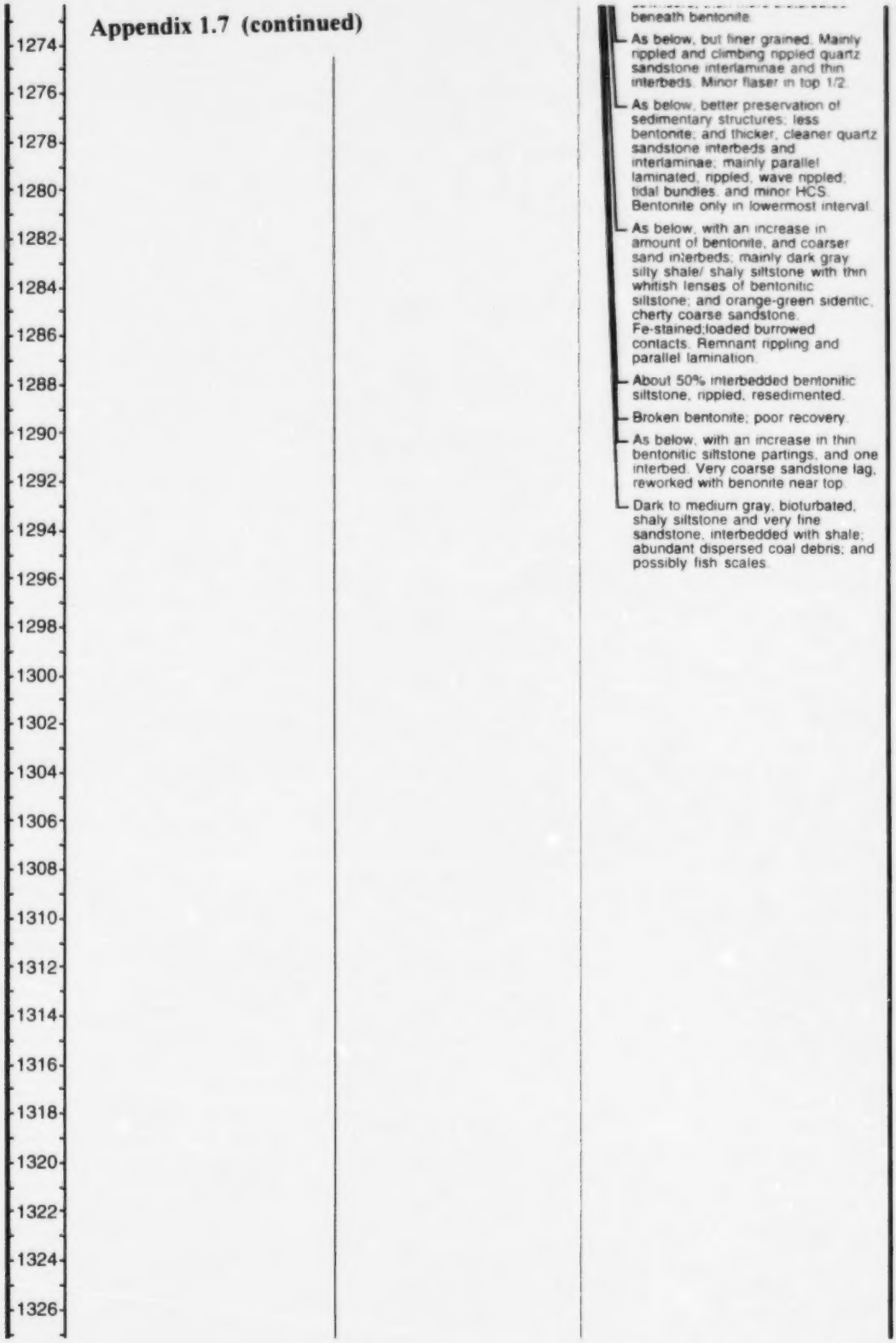
Fe Sid
As below. Dark-medium gray shaly siltstone/ silty shale, micaceous. Few scattered fish scales in upper 2/3, with a concentrated fish scale lag at 1/2 way down core. Isolated fish spines as indicated. Calcarenite interbed, underlain by highly fractured, calcite-filled fractures, at about 0.3 m below top. ? Faulted.
This calcite rich zone seems to be a replaced calcified bentonite.
As below. Dark-medium gray sahly siltstone/ silty shale, micaceous. Few scattered fish scales in upper half.
As below. Slightly more micaceous; no noticeable fish scales. Possible ammonite shell detritus near top.
As below. Slightly more micaceous; no noticeable fish scales.
As below, finer grained
Dark gray silty shale/shaly siltstone; minor sideritic sandstone interbeds, cherty, towards the base. Scattered fish scales.
BARONS SAND
Core 7 Missing.
As below, becoming finer grained upcore.
Broken bentonite.
Tan siltstone interbeds.
As below, with thicker broken bentonitic interval towards base.
As below, somewhat finer grained and slightly more micaceous.
Light tan- white siltstone, interbedded with gray to dark gray shaly siltstone; bentonitic about 1/2 downcore, then more bioturbated

Appendix 1.7 (continued)


1274
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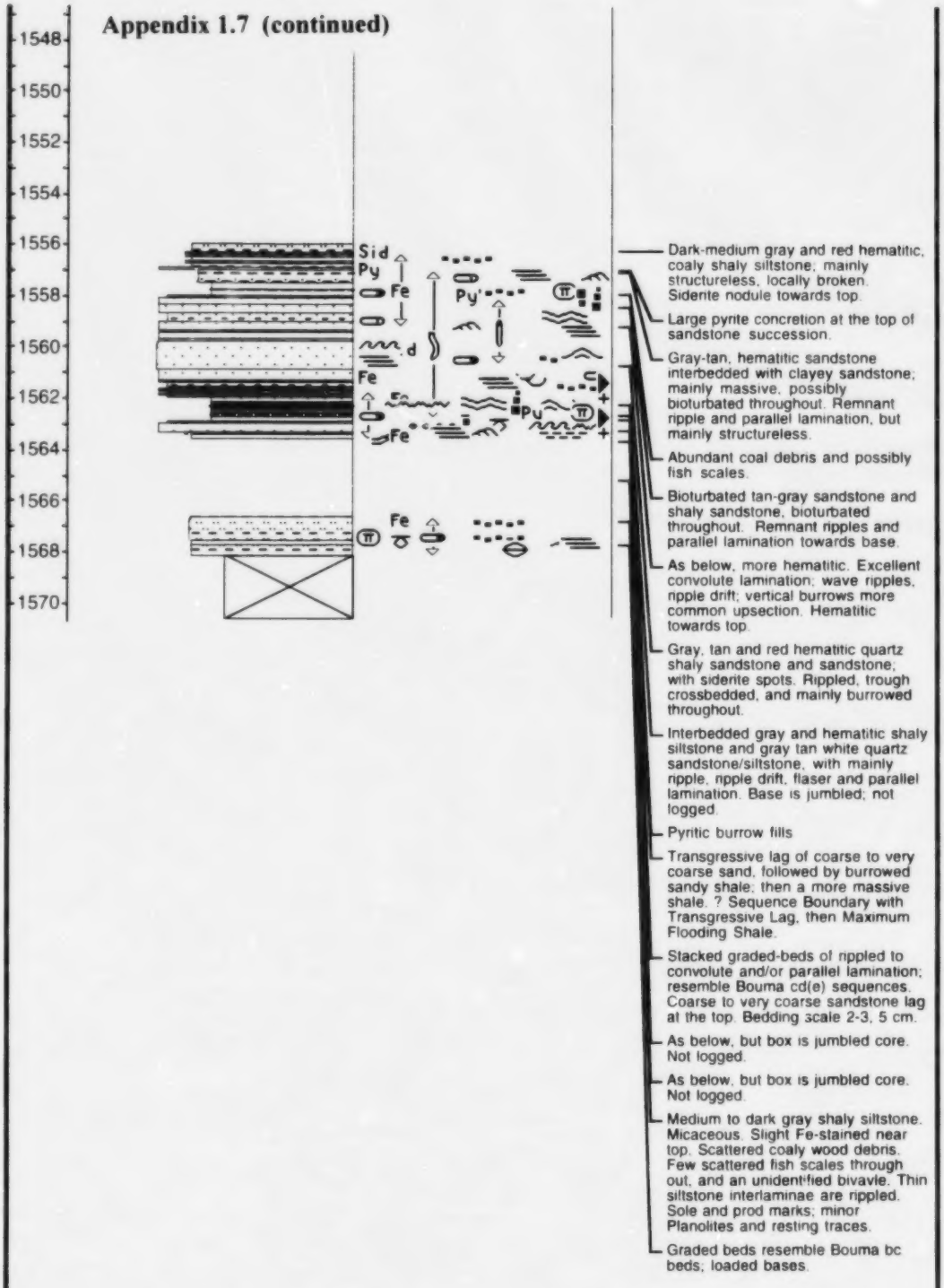
beneath bentonite.
As below, but finer grained. Mainly rippled and climbing rippled quartz sandstone interlaminae and thin interbeds. Minor flaser in top 1/2.
As below, better preservation of sedimentary structures; less bentonite; and thicker, cleaner quartz sandstone interbeds and interlaminae; mainly parallel laminated, rippled, wave rippled, tidal bundles, and minor HCS. Bentonite only in lowermost interval.
As below, with an increase in amount of bentonite, and coarser sand interbeds; mainly dark gray silty shale/ shaly siltstone with thin whitish lenses of bentonitic siltstone; and orange-green sidentic, cherty coarse sandstone. Fe-stained;loaded burrowed contacts. Remnant rippling and parallel lamination.
About 50% interbedded bentonitic siltstone, rippled, resedimented.
Broken bentonite; poor recovery.
As below, with an increase in thin bentonitic siltstone partings, and one interbed. Very coarse sandstone lag, reworked with benonite near top.
Dark to medium gray, bioturbated, shaly siltstone and very fine sandstone, interbedded with shale; abundant dispersed coal debris; and possibly fish scales.

Appendix 1.7 (continued)


1548
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Fe
Dark-medium gray and red hematitic, coaly shaly siltstone; mainly structureless, locally broken. Siderite nodule towards top.
Large pyrite concretion at the top of sandstone succession.
Gray-tan, hematitic sandstone interbedded with clayey sandstone; mainly massive, possibly bioturbated throughout. Remnant ripple and parallel lamination, but mainly structureless.
Abundant coal debris and possibly fish scales.
Bioturbated tan-gray sandstone and shaly sandstone, bioturbated throughout. Remnant ripples and parallel lamination towards base.
As below, more hematitic. Excellent convolute lamination; wave ripples, ripple drift; vertical burrows more common upsection. Hematitic towards top.
Gray, tan and red hematitic quartz shaly sandstone and sandstone; with siderite spots. Rippled, trough crossbedded, and mainly burrowed throughout.
Interbedded gray and hematitic shaly siltstone and gray tan white quartz sandstone/siltstone, with mainly ripple, ripple drift, flaser and parallel lamination. Base is jumbled; not logged.
Pyritic burrow fills
Transgressive lag of coarse to very coarse sand, followed by burrowed sandy shale; then a more massive shale. ? Sequence Boundary with Transgressive Lag, then Maximum Flooding Shale.
Stacked graded-beds of rippled to convolute and/or parallel lamination; resemble Bouma cd(e) sequences. Coarse to very coarse sandstone lag at the top. Bedding scale 2-3, 5 cm.
As below, but box is jumbled core. Not logged.
As below, but box is jumbled core. Not logged.
Medium to dark gray shaly siltstone. Micaceous. Slight Fe-stained near top. Scattered coaly wood debris. Few scattered fish scales through out, and an unidentified bivavle. Thin siltstone interlaminae are rippled. Sole and prod marks; minor Planolites and resting traces.
Graded beds resemble Bouma bc beds; loaded bases.

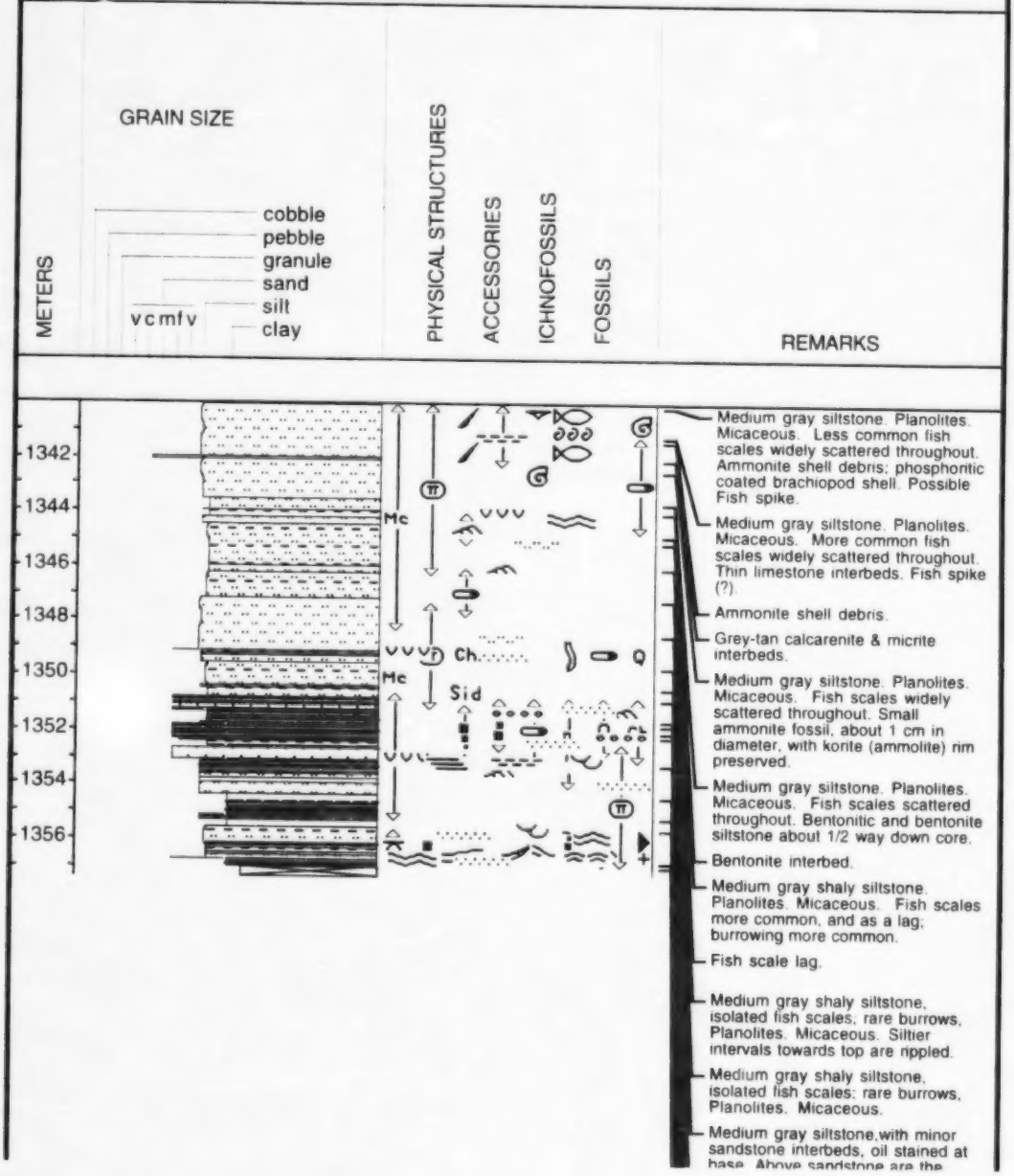
Penn West et al Barons

08-25-12-24w4

Date logged: January 7, 1998

Logged by: F. J. Hein

Remarks: Barons Sand is from 1350 - 1358.2 m; recovered 17.32 m. Top of 2nd White Specks is at 1260 m, so is not cored. Core starts about 6 m above Base of Fish Scales; fish scales throughout cored interval.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cobble
pebble
granule
sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
1342
1344
1346
1348
1350
1352
1354
1356
Mc
Mc
Ch
Sid
Medium gray siltstone. Planolites. Micaceous. Less common fish scales widely scattered throughout. Ammonite shell debris; phosphoritic coated brachiopod shell. Possible Fish spike.
Medium gray siltstone. Planolites. Micaceous. More common fish scales widely scattered throughout. Thin limestone interbeds. Fish spike (?).
Ammonite shell debris.
Grey-tan calcarenite & micrite interbeds.
Medium gray siltstone. Planolites. Micaceous. Fish scales widely scattered throughout. Small ammonite fossil, about 1 cm in diameter, with korite (ammolite) rim preserved.
Medium gray siltstone. Planolites. Micaceous. Fish scales scattered throughout. Bentonitic and bentonite siltstone about 1/2 way down core.
Bentonite interbed.
Medium gray shaly siltstone. Planolites. Micaceous. Fish scales more common, and as a lag; burrowing more common.
Fish scale lag.
Medium gray shaly siltstone, isolated fish scales; rare burrows, Planolites. Micaceous. Siltier intervals towards top are rippled.
Medium gray shaly siltstone, isolated fish scales; rare burrows, Planolites. Micaceous.
Medium gray siltstone,with minor sandstone interbeds, oil stained at base. Above sandstone are the

Appendix 1.8 (continued)

isolated scattered fish scale withinthe siltstone.

Medium to dark shaly siltstone, increase in percentage of fish scales. Very minor disseminated bentonite blebs, much more micaceous; and v. thin partings of bentonitic siltstone. Burrow intensity decreases.

Siltstone, red-brown; ? sideritic +/- oil stained.

Mixed granule, conglomeratic sandstone/ shale-siltstone; with bentoniteinterbeds and interlaminae. Increase in proportion of chert fragments. Level of bioturbation increasing. Some oil staining as below. Scattered fish scales within finer intervals.

BARONS SAND

Disseminated bentonite within interbeds and as burrow fills.

Concentrated bentonite interbed.

Dirty sandstone, oil stained, overlain and interbedded with medium gray shaly siltstone/silty shale. About 40% from the top of the box, the fish scales die out, and more pronounced coarse sand filled burrows become common on bedding surfaces. Composition of sand fraction becomes more black chert rich, and sorting is poor to very poor. Bentonite continues to be a noticebale component to the coarser interbeds.

Coarse to very coarse sand interbeds.

Medium to dark gray siltstone, sandy, with concentrations along bedding of fish scale lags. Minor interbedded rippled siltstones, bentonitic. Fracture pattern on siltstones is more pronounced than underlying units where it is shalier. Pronounced ridges with up to 1-2 cm relief on bedding surfaces due to fracture pattern. Sole marks common.

Dark - medium gray interlaminated fine siltstone and silty shale; with bentonitic siltstone interbeds (resedimented bentonite), scattered blebs of bentonite within silty shale, and thicker bentonite interbed within lower 25% of core. Prod marks and sole marks on bedding planes.

Bentonite interbeds.

As below, with less sandstone percentage. Slightly more siltstone than shale within finer beds.

Medium gray shale, sandy, with white sand interlaminae, coarsening-upwards into a white-gray sandstone. Sandstone interlaminae and interbeds are parallel laminated, sharp based, with also small-scale HCS, superimposed ripples. At the top the thickest sandstone is about 8 cm thick. Base and top bedding surfaces have prod marks, and other indistinct sole marks, and possibly indistinct burrows, but a predominance of physical sole marks and few if any biological.

Disseminated fish scales throughout shalier interval.

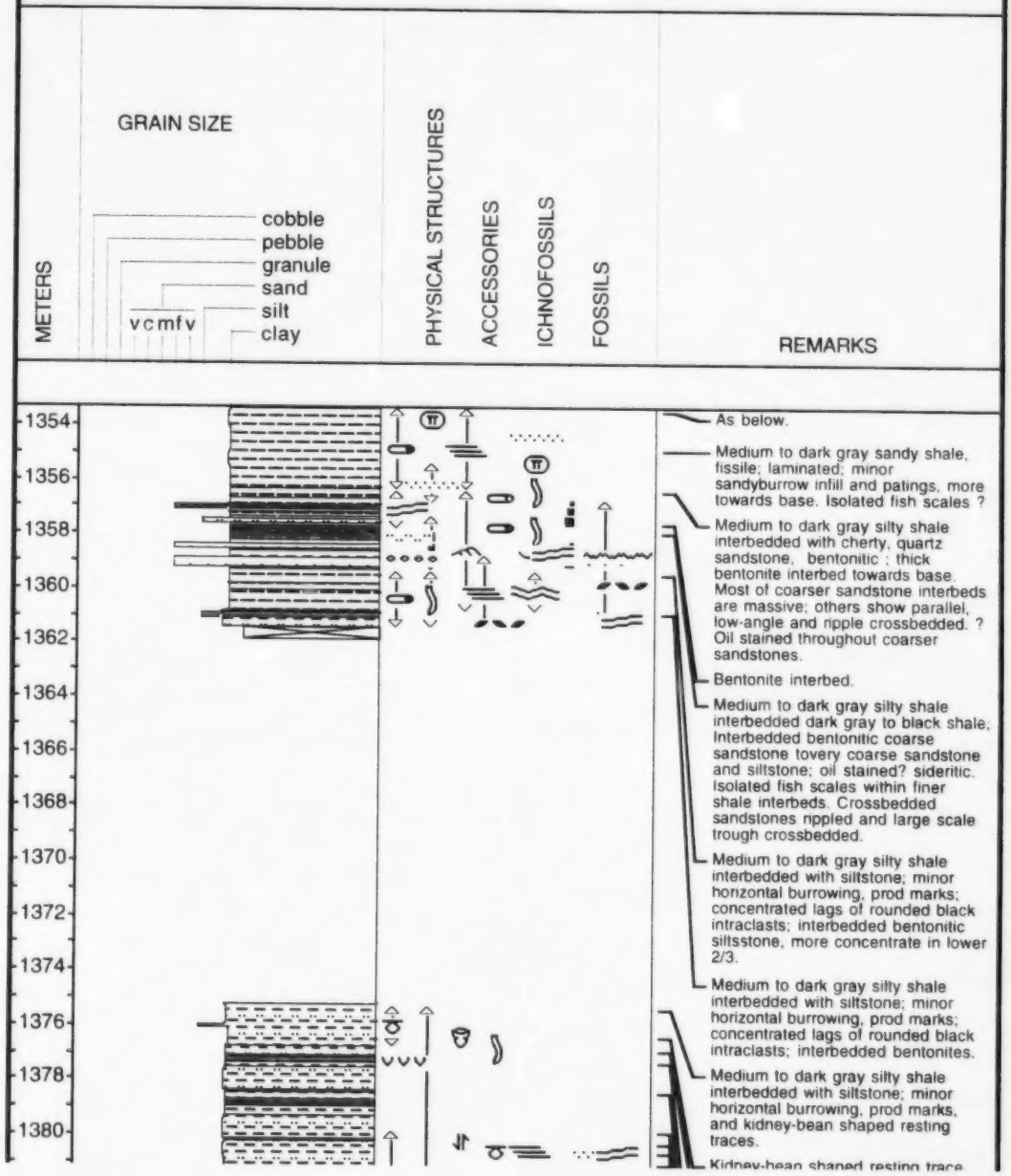
CanHunter Carmangsay

10-25-12-24w4

Date logged: January 8, 1998

Logged by: F. J. Hein

Remarks: Bow Island, mainly marine with some fluvial at the base.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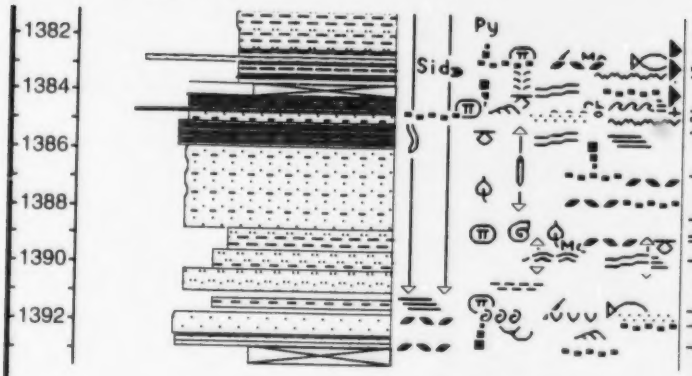
sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
1354
1356
1358
1360
1362
1364
1366
1368
1370
1372
1374
1376
1378
1380
As below.
Medium to dark gray sandy shale, fissile; laminated; minor sandyburrow infill and patings, more towards base. Isolated fish scales ?
Medium to dark gray silty shale interbedded with cherty, quartz sandstone, bentonitic ; thick bentonite interbed towards base. Most of coarser sandstone interbeds are massive; others show parallel, low-angle and ripple crossbedded. ? Oil stained throughout coarser sandstones.
Bentonite interbed.
Medium to dark gray silty shale interbedded dark gray to black shale. Interbedded bentonitic coarse sandstone tovery coarse sandstone and siltstone; oil stained? sideritic. Isolated fish scales within finer shale interbeds. Crossbedded sandstones rippled and large scale trough crossbedded.
Medium to dark gray silty shale interbedded with siltstone; minor horizontal burrowing, prod marks; concentrated lags of rounded black intraclasts; interbedded bentonitic siltsstone, more concentrate in lower 2/3.
Medium to dark gray silty shale interbedded with siltstone; minor horizontal burrowing, prod marks; concentrated lags of rounded black intraclasts; interbedded bentonites.
Medium to dark gray silty shale interbedded with siltstone; minor horizontal burrowing, prod marks, and kidney-bean shaped resting traces.
Kidney-bean shaped resting trace

Appendix 1.9 (continued)



As below, slightly more silty upsection, with more obvious horizontal burrows, very fine sand/siltstone interbeds;and one thicker coarse sandstone interbed.

White/gray coarse sandstone interbed, ? bentonitic, with quartz and chert clasts.

As below, minor gray very fine sandstone/siltstone interbeds in upper half.

As below, medium to dark gray shale/silty shale. Minor to rare bioturbation, mainly horizontal burrows, prod marks and resting traces. No obvious fish scales in core. Prominent slickensides about 1/2 way downcore.

Tan-grey siltstone interbed.

Sandstone interbeds, low angle and parallel laminated, with loaed and bioturbated bases.

Medium to dark gray shale/silty shale. Minor to rare bioturbation, mainly horizontal burrows, prod marks and resting traces. Pyrite/chalcopyrite replacement of burrow fill material. No obvious fish scales in core.

BOW ISLAND

Conglomeratic lags, at about 1/2 way through core, thin chert pebble conglomerate lag, well rounded; upper conglomerate is thicker, with siderite siltstone, clay intraclasts, and chert pebble conglomerate.

Light grey, clean quartz sandstone interbedded with medium to dark shale, bioturbated in finer interbeds with vertical and oblique burrows. Graded-laminations, tial couplets (?), HCH and SCS upsection in coarser sanstone part.

Isolated rounded chert pebble.

Grayshaly sand with isolated black cert pebble, well rounded. Poorly sorted. ? Cherty quartz sandstone.

Tan siltstone, massive, broken core.

Broken Core. Chert pebble conglomerate lag, with black, red and green chert clasts, up to 3 cm long, well rounded. rayquartz and chert clst sandstone matrix, poorlly sorted. [? Transgressive Lag].

As below, Gray bioturbated shaly sandstone, with scattered wood debris and black shale intraclasts. Intensely bioturbated, with a dominant percentage of vertical burrows, less oblique and horizontalgrading up into cleaner sandstones, with less shale clasts; low-angle to horizontal lamination, less burrowed. [High Enery Marine].

Gray-tan bioturbated shaly sandstone, with scattered wood debris and black shale intraclasts. Intensely bioturbated, witha dominant percentage of vertical burrows, less oblique and horizontal. [High Enery Marine].

Bioturbated grey quartz shaly sandstone. Parallel laminated, bioturbated contacts. Scattered fish scales, an a chitinous shiny (? scale or detritus from ammonite shells. [Medium Energy Marine]

Corcentrated coaly detritus, intraclasts, and woody debris at base.

Interlaminated dark gray shaly

Appendix 1.9 (continued)

- siltstone and silty shale, alternating with grey quartz sandstone. Parallel laminated, bioturbated and loaded contacts. Minor low-angle and rippling. [Low Energy Marine]
- Dark - medium gray sandy silty shale, bioturbated, overlain by laminated siltstone and shale, rippled and parallel laminated. Planolites and delicate laminations [Low energy marine environment].
- Dark gray to black silty clay; scattered fish scales throughout; fish spines.
- Tan-grey quartz sandstone, scattered black intraclasts and/or coaly detritus; possible mollusc (?) type shell cast; top 0.3 of the unit is highly broken, with bentonitic chunks, isolated fish scale within dark shale interlaminae, possibly fallen in from above. [Fluvial Sandstone?].
- Gray to tan, quartz sandstone, with concentrated very black shale clasts at the base (with possibly organic coaly detritus). Vague ripple and/or trough crossbedding [could be Fluvial Channel succession].

Appendix 1.10

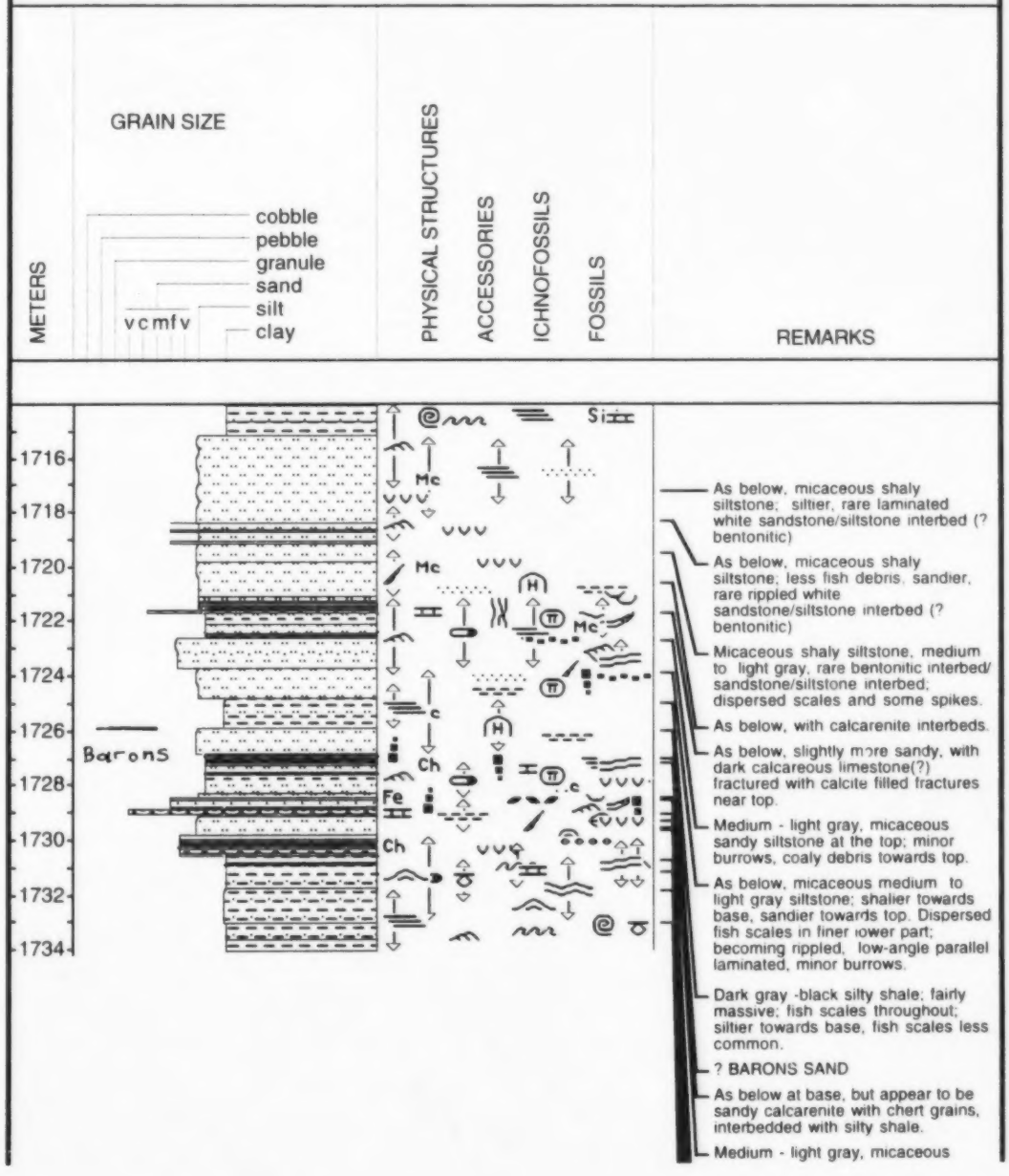
Crestar 100 Claresholm

06-26-13-26w4

Date logged: January 19, 1998

Logged by: F. J. Hein

Remarks: Dominantly sandy shale, bentonitic, with thicker Barons Sands towards base. Some of the sandstones are very calcareous, cement or actually calcarenites. Top calcite fracture fills as in another well already logged. Interbedded dark limestone towards top.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pebble
granule
sand
silt
clay
vcmfv
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
1716
1718
1720
1722
1724
1726
1728
1730
1732
1734
Barons
Si
Mc
Ch
Fe
As below, micaceous shaly siltstone; siltier, rare laminated white sandstone/siltstone interbed (? bentonitic)
As below, micaceous shaly siltstone; less fish debris, sandier, rare rippled white sandstone/siltstone interbed (? bentonitic)
Micaceous shaly siltstone, medium to light gray, rare bentonitic interbed/ sandstone/siltstone interbed; dispersed scales and some spikes.
As below, with calcarenite interbeds.
As below, slightly more sandy, with dark calcareous limestone(?) fractured with calcite filled fractures near top.
Medium - light gray, micaceous sandy siltstone at the top; minor burrows, coaly debris towards top.
As below, micaceous medium to light gray siltstone; shalier towards base, sandier towards top. Dispersed fish scales in finer lower part; becoming rippled, low-angle parallel laminated, minor burrows.
Dark gray -black silty shale; fairly massive; fish scales throughout; siltier towards base, fish scales less common.
? BARONS SAND
As below at base, but appear to be sandy calcarenite with chert grains, interbedded with silty shale.
Medium - light gray, micaceous

Appendix 1.10 (continued)

shaly siltstone at the top; minor burrows, definite fish scales dispersed throughout, bentonitic siltstone/coarse sandstone interbeds; becoming very calcite-cemented in coarse sandstone near top.

- Medium - light gray, micaceous shaly siltstone at the top; minor burrows, and possible sideritized/coated fish scale (?)
- Broken core, as below coarse granular sandstone; rippled, flaser ?, towards base, oil stained. Shaly partings throughout, crossbedded, intraclasts at top.
- Bentonitic coarse granule sand interbedded with dark gray shale, coarsening upwards into fine granule conglomerate, calcareous cemented at base, oil stained at top; overlain abruptly by coarse sandstone, oil stained interbedded with medium gray shaly siltstone/silty shale.
- Dark gray-brown siltstone, micaceous. Few dispersed fish spines, bivalves less than 0.4 mm across. No clear fish scales. Bentonitic parting on bedding.
- Calcareous and bentonitic coarser interbeds, poorly sorted, rippled, burrowed, dark clasts (? chert), salt and pepper sandstone.
- Increase in wave ripples, ripples, convolute lamination, lenticular-wispy ripple crossbedding; bentonitic shale (?) has a greasy feel, and light grey colour.
- Calcarenite interbeds, isolated ripple formsets, and parallel laminated.
- As below, with slightly thicker sandstone interbeds (up to 3 cm), with increase in wave ripples, low angle crossbedding, and prominent flute marks. Slight horizontal bioturbation.
- Dark - medium gray shale, sandy, with minor calcarenite slump beds at 60% downbox and near top. Mainly rippled, parallel laminated, with sole marks and little bioturbation.

Appendix 1.11

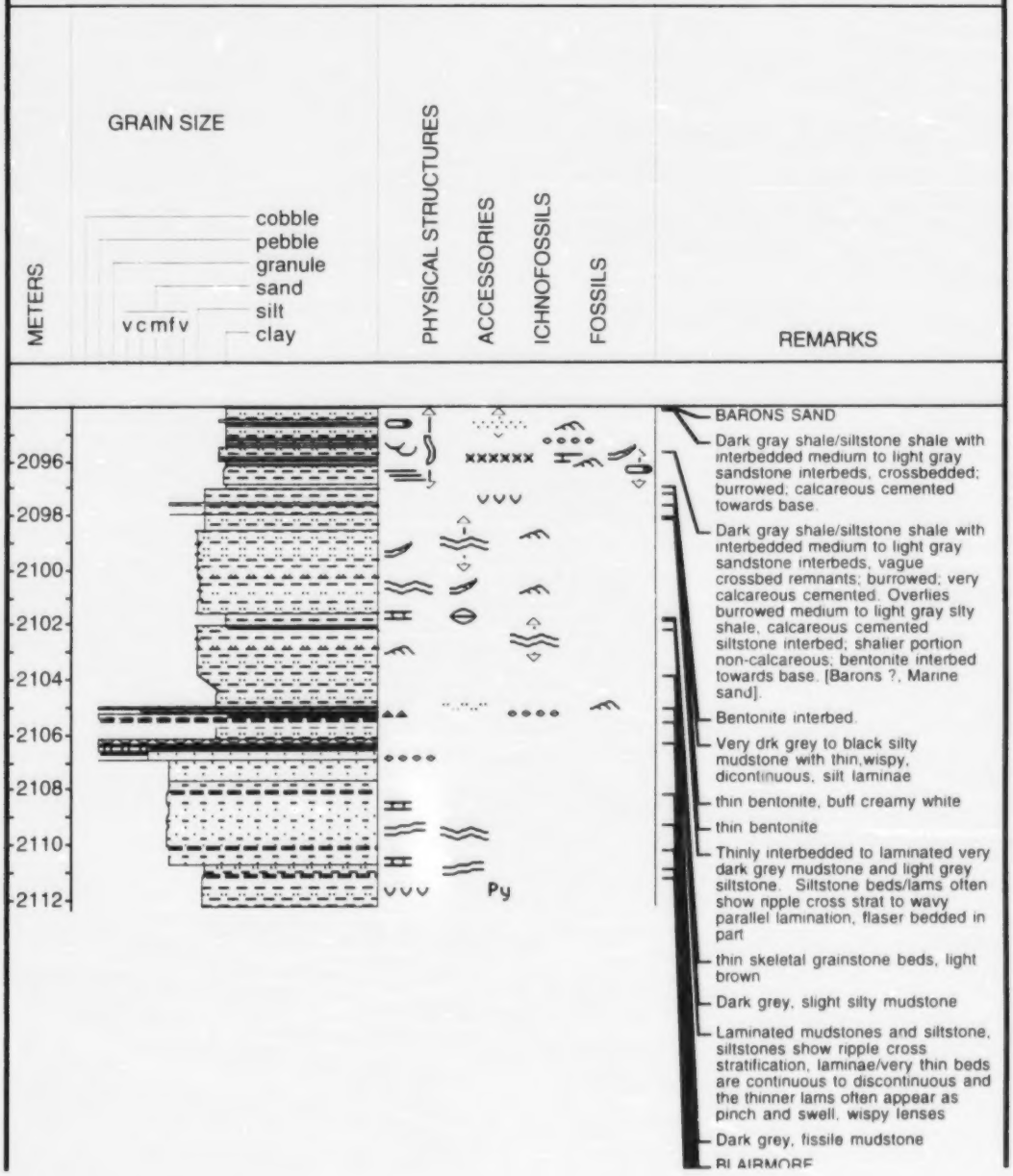
Sinclair C and E DAHL 2A

03-07-13-27w4

Date logged: January 21, 1998

Logged by: F. J. Hein

Remarks: Thin Barons Sands interbedded with shales and bentonites within zone containing fish scales, and Blairmore Group conglomerate, sandstones/shale. Top of Barons Sands at 2090 m.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GRAIN SIZE
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pebble
granule
sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
2096
2098
2100
2102
2104
2106
2108
2110
2112
Py
BARONS SAND
Dark gray shale/siltstone shale with interbedded medium to light gray sandstone interbeds, crossbedded; burrowed; calcareous cemented towards base.
Dark gray shale/siltstone shale with interbedded medium to light gray sandstone interbeds, vague crossbed remnants; burrowed; very calcareous cemented. Overlies burrowed medium to light gray silty shale, calcareous cemented siltstone interbed; shalier portion non-calcareous; bentonite interbed towards base. [Barons ?, Marine sand].
Bentonite interbed.
Very drk grey to black silty mudstone with thin,wispy, dicontinuous, silt laminae
thin bentonite, buff creamy white
thin bentonite
Thinly interbedded to laminated very dark grey mudstone and light grey siltstone. Siltstone beds/lams often show ripple cross strat to wavy parallel lamination, flaser bedded in part
thin skeletal grainstone beds, light brown
Dark grey, slight silty mudstone
Laminated mudstones and siltstone, siltstones show ripple cross stratification, laminae/very thin beds are continuous to discontinuous and the thinner lams often appear as pinch and swell, wispy lenses
Dark grey, fissile mudstone
BLAIRMORE

Appendix 1.11 (continued)

Grain to matrix supported, chert pebble conglomerate with thin coarse sand and mudstone interbeds
Very dark grey to black silty mudstone, thin siltstone laminae
Dominantly grain supported chert pebble conglomerate with interbeds of chert pebbly sandstone, slightly calcareous
Burrow mottled shaly sandstone, primary stratification obliterated, difficult do discern individual traces, some sub-vertical cross cutting burrows, slightly calcareous
Low angle to wavy bedded, cross stratified, amalgamated sandstone
Burrow mottled shaly sandstone
Low angle, interlaminated siltstone and mudstone, rare biotubation
Medium greenish grey mudstone (all rubble), pyritic and appear to be very bentonitic, fissile in part (asso. w/ bentonitic portions) to indurated

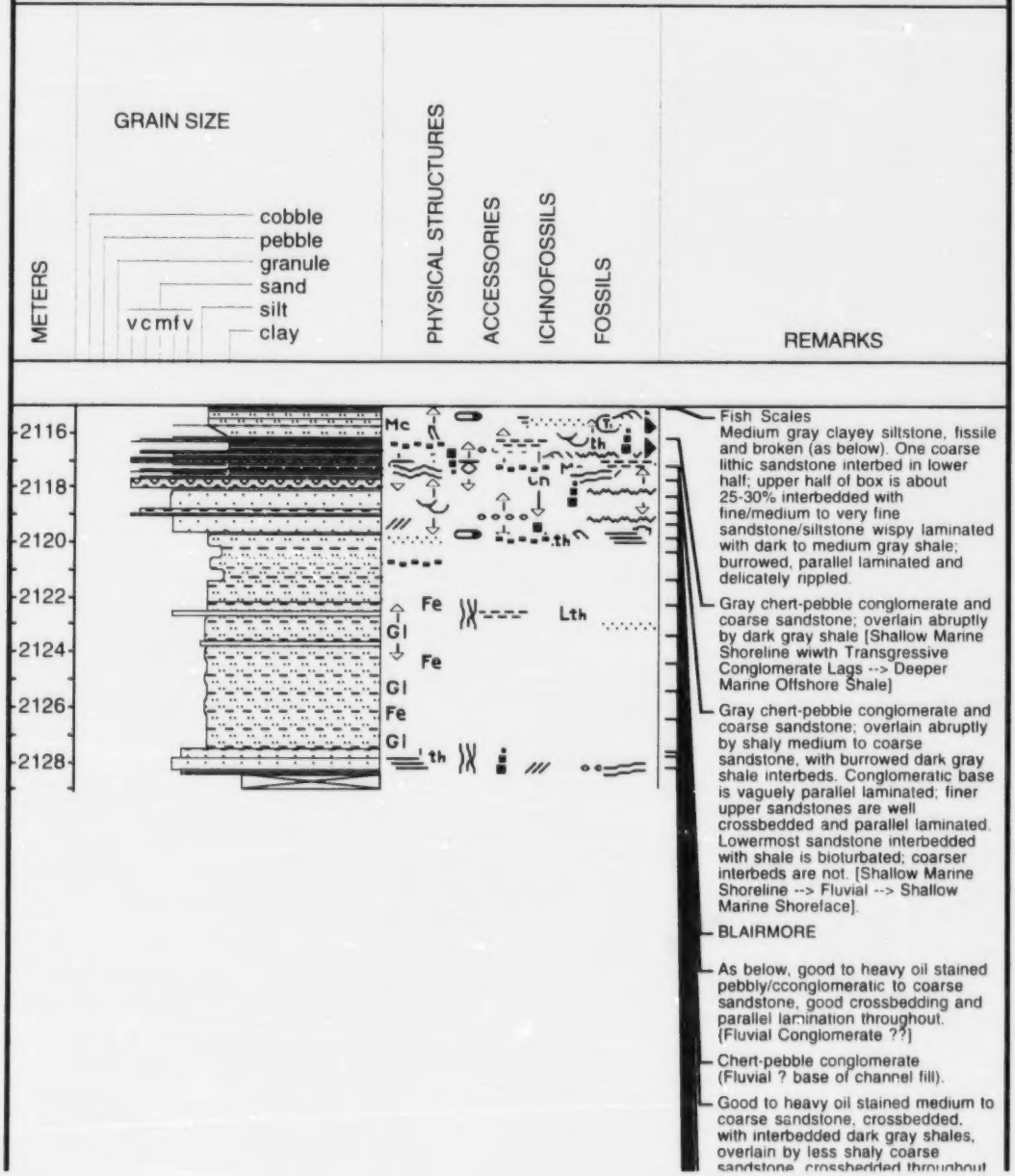
Ranger et al Claresholm

11-20-13-27w4

Date logged: January 27, 1998

Logged by: F. J. Hein

Remarks: Blairmore conglomeratic sandstone --> Lower Colorado (?Base of Fish Scales) shale with thin sandstone interbeds (Upper Bow Island). Mainly fluvial Blairmore Grp.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pebble
granule
sand
silt
clay
v c m f v
PHYSICAL STRUCTURES
ACCESSORIES
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FOSSILS
REMARKS
2116
2118
2120
2122
2124
2126
2128
Mc
Fe
Gl
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th
Fish Scales
Medium gray clayey siltstone, fissile and broken (as below). One coarse lithic sandstone interbed in lower half; upper half of box is about 25-30% interbedded with fine/medium to very fine sandstone/siltstone wispy laminated with dark to medium gray shale; burrowed, parallel laminated and delicately rippled.
Gray chert-pebble conglomerate and coarse sandstone; overlain abruptly by dark gray shale [Shallow Marine Shoreline wiwth Transgressive Conglomerate Lags --> Deeper Marine Offshore Shale]
Gray chert-pebble conglomerate and coarse sandstone; overlain abruptly by shaly medium to coarse sandstone, with burrowed dark gray shale interbeds. Conglomeratic base is vaguely parallel laminated; finer upper sandstones are well crossbedded and parallel laminated. Lowermost sandstone interbedded with shale is bioturbated; coarser interbeds are not. [Shallow Marine Shoreline --> Fluvial --> Shallow Marine Shoreface].
BLAIRMORE
As below, good to heavy oil stained pebbly/cconglomeratic to coarse sandstone, good crossbedding and parallel lamination throughout. (Fluvial Conglomerate ??)
Chert-pebble conglomerate (Fluvial ? base of channel fill).
Good to heavy oil stained medium to coarse sandstone, crossbedded, with interbedded dark gray shales, overlain by less shaly coarse sandstone, crossbedded throughout

Appendix 1.12 (continued)

[Overbank --> Shoreline/Shoreface --> Fluvial Sandstone ?]

- Broken core interval of mixed lithologies, including gray-tan siltstone/clayey siltstone; tan-maroon siltstone with coal woody fragments; gray siltstone; red-maroon siltstone; ochre-gray dirty lithic thin sandstone (2-3 cm); and salt-and-pepper gray medium to coarse sandstone at the top.
- Broken medium-light gray clayey siltstone/ silty claystone, highly broken. Isolated coaly detritus, wood fragment, about 1/2 way down box. (Fluvial Overbank?)
- Broken medium gray clayey siltstone/ silty claystone, highly broken. (Fluvial Overbank?)
- Broken green/gray sandy clayey siltstone. At top is a dirty sandstone, coarse with lithics; fracture infilled with maroon clay. No obvious trace fossils. Top part is maroon-caste gray clayey siltstone, highly broken. (Fluvial Overbank?)
- Broken green/gray clayey siltstone. More coherent green-gray siltstone chunks. No obvious trace fossils. (Fluvial Overbank?)
- Broken green to maroon clayey siltstone. Minor siltstone chunks. No obvious trace fossils. (Fluvial Overbank?)
- Broken maroon to green clayey siltstone. Minor siltstone chunks. No obvious trace fossils. (Fluvial Overbank?)
- Broken green to maroon clayey siltstone. No obvious trace fossils. (Fluvial Overbank?)
- Dark gray, muddy sandstone, with red-maroon clayey matrix fill.
- Medium gray salt and pepper, but lithics lower percentage, medum to coarse sandstone, vague parallel laminated or crossbedded, becomming muddier (dirtier, less sorted upsection), with odd green and red-maroon clays as irregular pore and fracture fills (? paleosol fracture fills), or drilling mud infilling pores and fractures. [? Fluvial Sandstone]
- Medium gray shaly sand, with vague parallel lamination, overlain by green caste-gray, salt and pepper, but lithics high percentage, coarse sandstone, crossbedded, with well-developed low angle to higher angle crossbedding. [? Fluvial Sandstone]

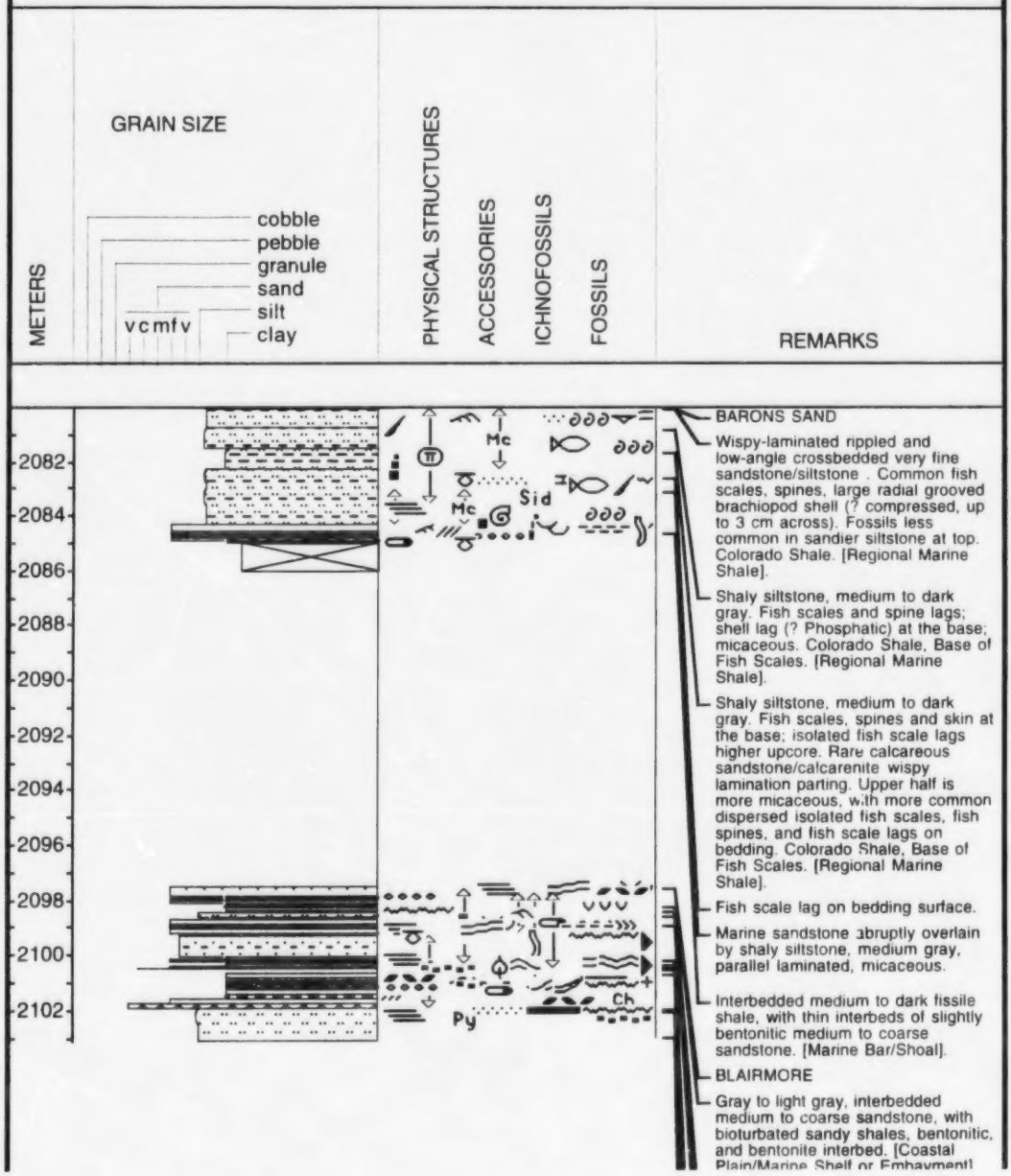
Can Hunter er al Claresholm

06-29-13-27w4

Date logged: Jnuary 23, 1998

Logged by: F. J. Hein

Remarks: ? lower part Bow Island --> good Bow Island/Blairmore; conglomeratic with interbedded bentonite; upper part is shales with thin sandstones and probably Barons Sand. Fluvial and offshore sediments.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PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
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REMARKS
2082
2084
2086
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2102
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Mc
Sid
Py
Ch
BARONS SAND
Wispy-laminated rippled and low-angle crossbedded very fine sandstone/siltstone . Common fish scales, spines, large radial grooved brachiopod shell (? compressed, up to 3 cm across). Fossils less common in sandier siltstone at top. Colorado Shale. [Regional Marine Shale].
Shaly siltstone, medium to dark gray. Fish scales and spine lags; shell lag (? Phosphatic) at the base; micaceous. Colorado Shale, Base of Fish Scales. [Regional Marine Shale].
Shaly siltstone, medium to dark gray. Fish scales, spines and skin at the base; isolated fish scale lags higher upcore. Rare calcareous sandstone/calcarenite wispy lamination parting. Upper half is more micaceous, with more common dispersed isolated fish scales, fish spines, and fish scale lags on bedding. Colorado Shale, Base of Fish Scales. [Regional Marine Shale].
Fish scale lag on bedding surface.
Marine sandstone abruptly overlain by shaly siltstone, medium gray, parallel laminated, micaceous.
Interbedded medium to dark fissile shale, with thin interbeds of slightly bentonitic medium to coarse sandstone. [Marine Bar/Shoal].
BLAIRMORE
Gray to light gray, interbedded medium to coarse sandstone, with bioturbated sandy shales, bentonitic, and bentonite interbed. [Coastal Plain/Marine Shelf or Embayment]

Appendix 1.13 (continued)

- Reworked bentonites.
- Reworked bentonites.
- Bentonite.
- Medium to dark gray bioturbated shaly salt and pepper sandstone, with abundant burrows; upsection sandstone interbed remnants better preserved with parallel lamination and rippled; capped by medium to coarse crossbedded salt and pepper sandstone, with rare burrows and possibly slight oil staining. Bow Island. [Marine Shelf --> Fluvial Channel Sand/Bay Mouth Bar; Coastal Plain Setting].
- As below, finer grained, with a transgressive lag at the base, more intense bioturbation; alternating with good crossbedded sandstones.
- [Offshore Marine Bar/Shoal].
- Buff/tan offshore shelf siltstone/very fine sandstone; vague parallel laminated, interbedded with bioturbated silty shale.
- Large branch/twig cast, v-shaped and tapered end.
- Transgressive lag, bioturbated into sandstone.
- Grey, chert pebble conglomerate, grading up into pebbly sanstone and sandstone, crosssbedded, some oil staining, in finer interbeds; becoming a salt and pepper coarse sandstone, with dark gray shale interbeds towards top, with bioturbation; intraclasts siltstone and shale; some shale/siltstone drapes on crossbedding. [Fluvial --> Estuarine].
- Mixed colour change to gray coarse sand mixed in with soft siltstone; very abundant wood and carbonaceous debris.
- Tan-buff, soft ? weathered; gray dirty siltstone,mainly massive, vague parallel lamination; noncalcareous. Towards base few partings of coaly detritus on bedding planes. Near top pyrite/chalcopyrite radial concretions, 0.5 cm diameter.
- Tan-buff gray dirty siltstone, massive; noncalcareous. [Offshore Shelf Sands?].

Appendix 1.14

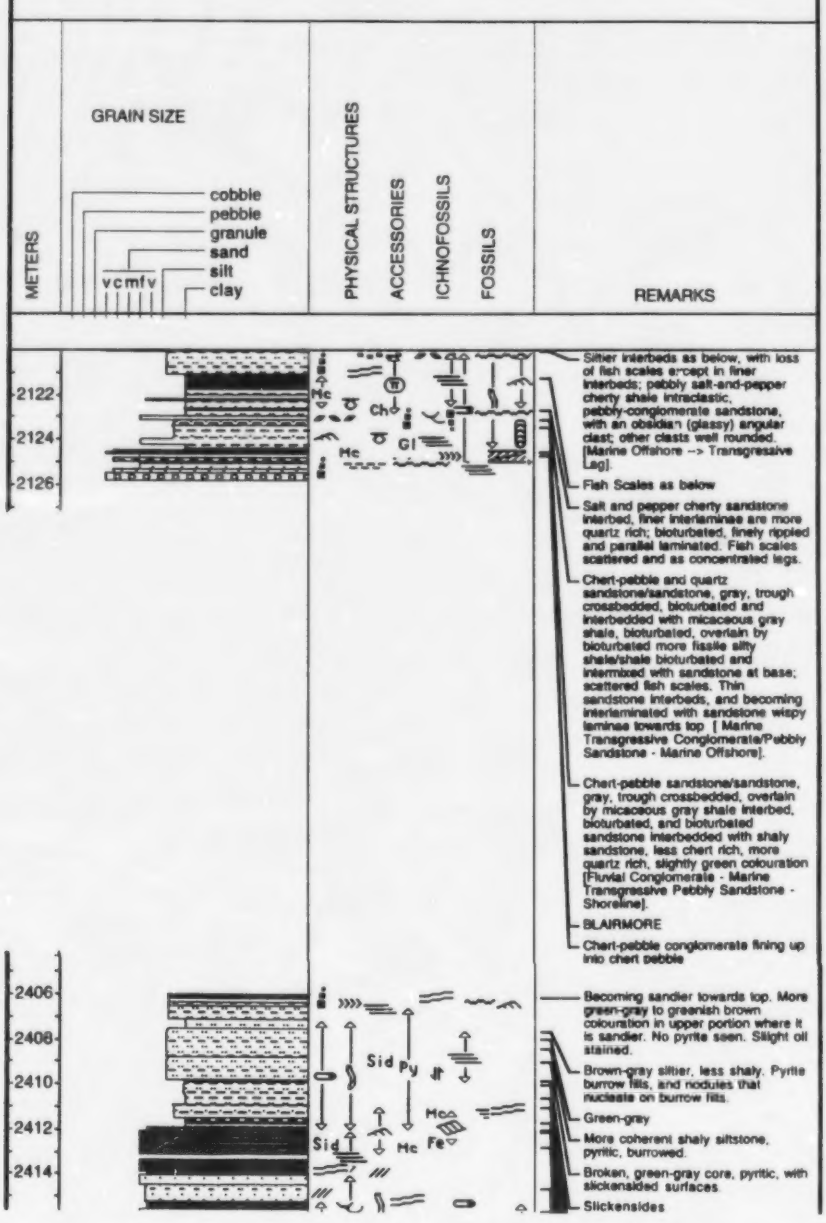
MLC DeKalb Claresholm

06-30-13-27w4

Date logged: January 26, 1998

Logged by: F. J. Hein

Remarks: Thin Barons in Colorado Shale, over thin Blairmore succession.


METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vcmfv
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
2122
2124
2126
Mc
Ch
Gl
Mc
Siltier interbeds as below, with loss of fish scales except in finer interbeds; pebbly salt-and-pepper cherty shale intraclastic, pebbly-conglomerate sandstone, with an obsidian (glassy) angular clast; other clasts well rounded. [Marine Offshore --> Transgressive Lag].
Fish Scales as below
Salt and pepper cherty sandstone interbed, finer interlaminae are more quartz rich; bioturbated, finely rippled and parallel laminated. Fish scales scattered and as concentrated lags.
Chert-pebble and quartz sandstone/sandstone, gray, trough crossbedded, bioturbated and interbedded with micaceous gray shale, bioturbated, overlain by bioturbated more fissile silty shale/shale bioturbated and intermixed with sandstone at base; scattered fish scales. Thin sandstone interbeds, and becoming interlaminated with sandstone wispy laminae towards top. [Marine Transgressive Conglomerate/Pebbly Sandstone - Marine Offshore].
Chert-pebble sandstone/sandstone, gray, trough crossbedded, overlain by micaceous gray shale interbed, bioturbated, and bioturbated sandstone interbedded with shaly sandstone, less chert rich, more quartz rich, slightly green colouration [Fluvial Conglomerate - Marine Transgressive Pebbly Sandstone - Shoreline].
BLAIRMORE
Chert-pebble conglomerate fining up into chert pebble
2406
2408
2410
2412
2414
Sid
Py
Mc
Fe
Sid
Mc
Becoming sandier towards top. More green-gray to greenish brown colouration in upper portion where it is sandier. No pyrite seen. Slight oil stained.
Brown-gray siltier, less shaly. Pyrite burrow fills, and nodules that nucleate on burrow fills.
Green-gray
More coherent shaly siltstone, pyritic, burrowed.
Broken, green-gray core, pyritic, with slickensided surfaces.
Slickensides

Appendix 1.15

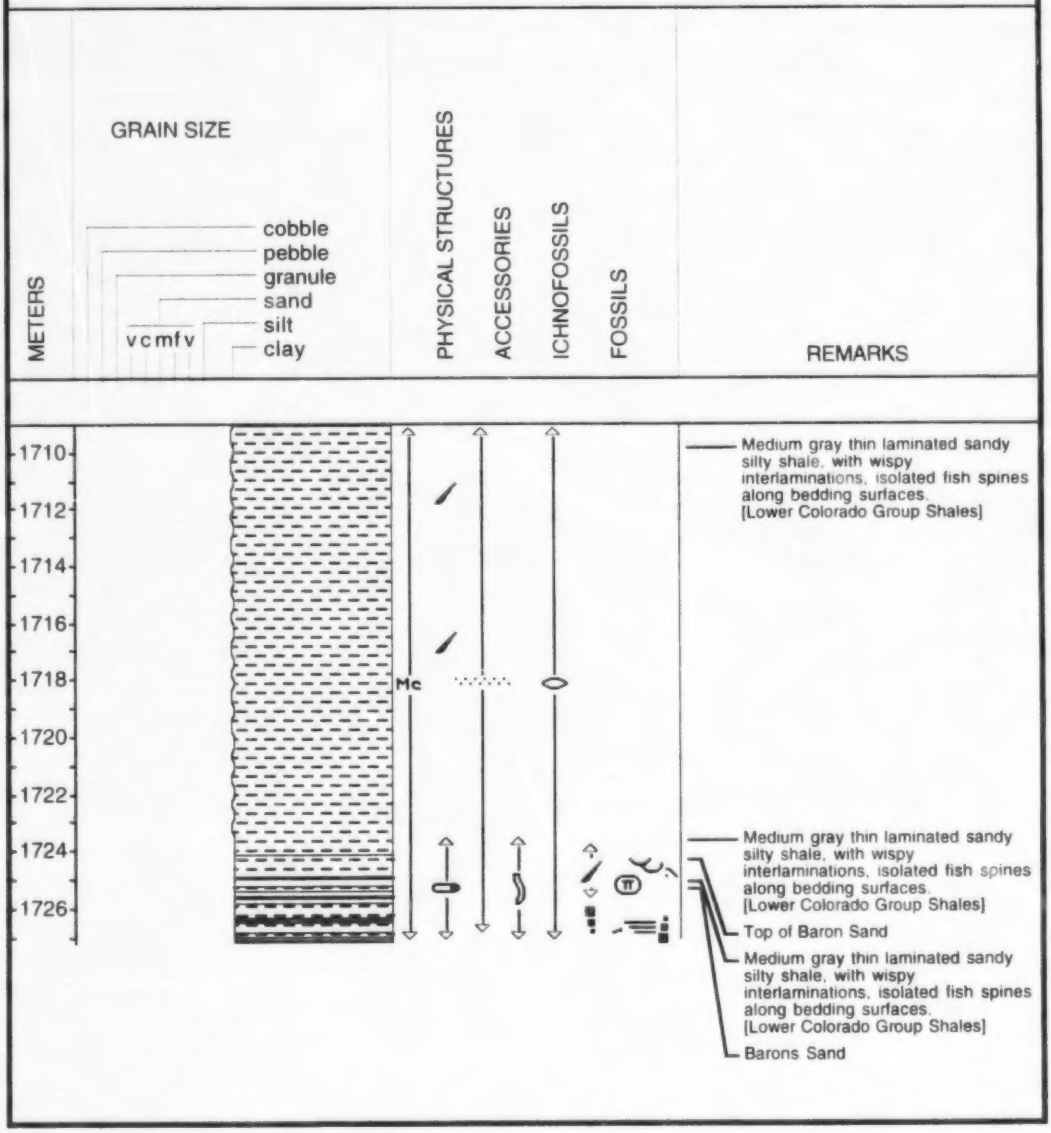
Crestar 100 Clareshold

03-34-13-26w4

Date logged: April 20, 1998

Logged by: F. J. Hein

Remarks: Barons Sand.



Appendix 1.16

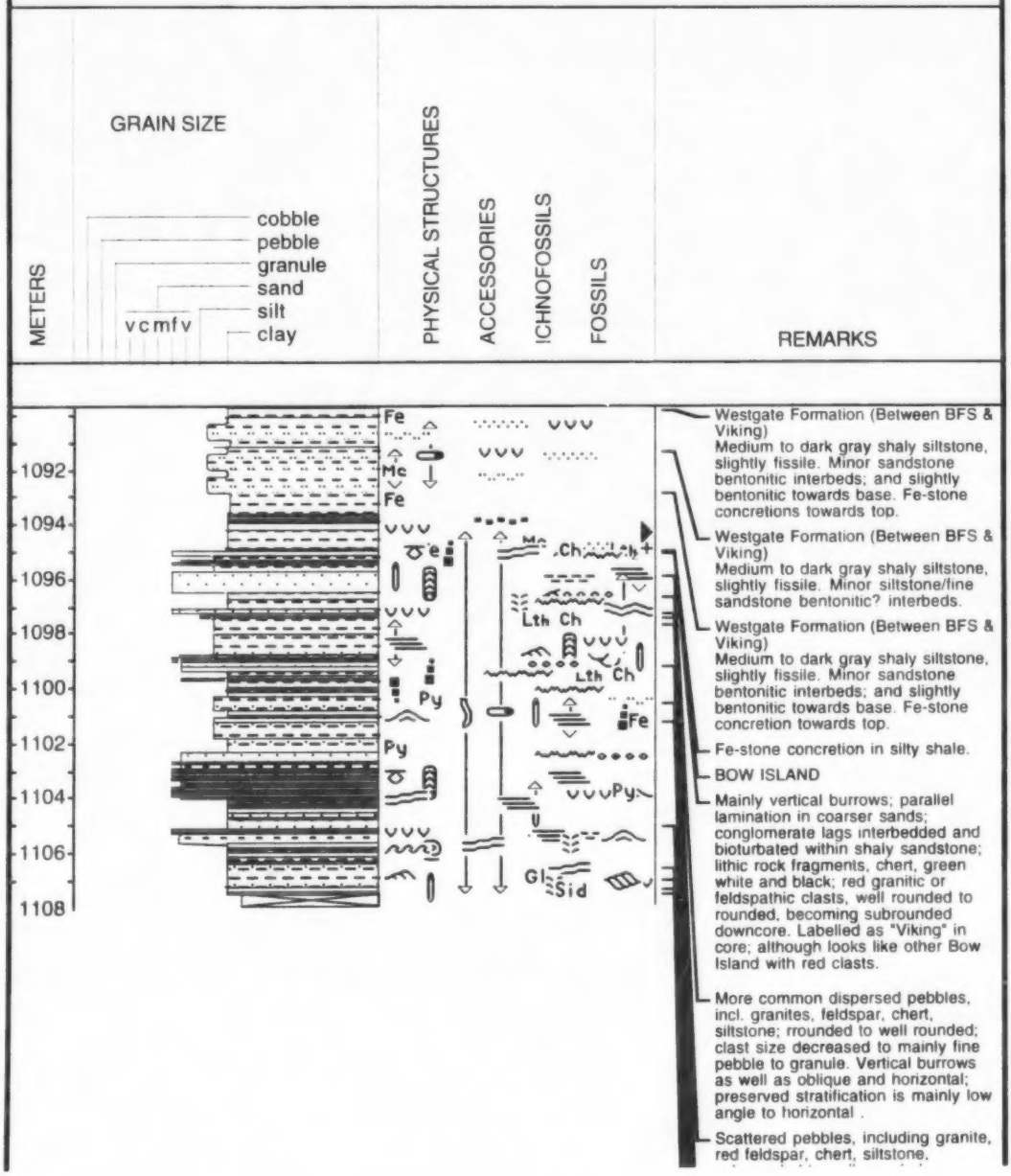
Westcourt McGregor

07-20-17-21w4

Date logged: January 28, 1998

Logged by: F. J. Hein

Remarks: Bioturbated sandy shale, with interbedded bentonites and ironstones; overlain by interbedded Bow Island sandstone and shale, to transgressive conglomerates (at least 3 pulses) capped by bentonite; overlain by lower Colorado Shale.


METERS
GRAIN SIZE
cobble
pebble
granule
sand
silt
clay
vcmfv
PHYSICAL STRUCTURES
ACCESSORIES
ICHNOFOSSILS
FOSSILS
REMARKS
1092
1094
1096
1098
1100
1102
1104
1106
1108
Fe
Mc
Py
Ch
Lth
Sid
Gl
Westgate Formation (Between BFS & Viking)
Medium to dark gray shaly siltstone, slightly fissile. Minor sandstone bentonitic interbeds; and slightly bentonitic towards base. Fe-stone concretions towards top.
Westgate Formation (Between BFS & Viking)
Medium to dark gray shaly siltstone, slightly fissile. Minor siltstone/fine sandstone bentonitic? interbeds.
Westgate Formation (Between BFS & Viking)
Medium to dark gray shaly siltstone, slightly fissile. Minor sandstone bentonitic interbeds; and slightly bentonitic towards base. Fe-stone concretion towards top.
Fe-stone concretion in silty shale.
BOW ISLAND
Mainly vertical burrows; parallel lamination in coarser sands; conglomerate lags interbedded and bioturbated within shaly sandstone; lithic rock fragments, chert, green white and black; red granitic or feldspathic clasts, well rounded to rounded, becoming subrounded downcore. Labelled as "Viking" in core; although looks like other Bow Island with red clasts.
More common dispersed pebbles, incl. granites, feldspar, chert, siltstone; rrounded to well rounded; clast size decreased to mainly fine pebble to granule. Vertical burrows as well as oblique and horizontal; preserved stratification is mainly low angle to horizontal .
Scattered pebbles, including granite, red feldspar, chert, siltstone.

Appendix 1.16 (continued)

subrounded to well rounded. [Reworked Transgressive Conglomerate in Medium Energy Shoreface]

Upper Shoreface Sandstone, with HCS?

Bentonite interbed at top

Dispersed chert, and lithics, including granite, feldspar, vein quartz; subrounded to well rounded.

Few pink/red granitic clasts.

Pyritic siltstone interbeds, diagenetic pyritic matrix

Fe-stone concretion

As below, slightly bentonitc, rare sandstone bed remnants preserved from complete bioturbation. [Low to Medium Energy Shoreface].

Bow Island
As below, with white, salt-and-pepper sandstone interbeds; low angle crossbedded; nipple and ripple drift remnants not disturbed by bioturbation; some of sandstones have good Skolithos, and escape burrows.
Slightly bentonitic about 1/4 down box, intermixed by bioturbation, and left as burrow infills. [Lower to Medium Energy Shoreface]

Green-caste, ? pyritic/lithic/glauconitic

As below, with dispersed granule clasts, including tan, ochre, white siltstone and chert, subround to well rounded; siderite (? Ochre) cemented concretions at the top
[Shallow Marine --> Transgressive Lag --> ? Hardground]

Medium gray sandy shale, bentonitic at the top, as reworked bentonite, lenticular resedimentd and possibly mixed in by burrowing.